FINAL REPORT

Improvement of Clupicker - Phase I

DLA900 87-0017,

Submitted by

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The redesigned Clupicker was based on the results of the systematic DFA analysis and the PDM analysis. This new design reduces the total number of parts from 80 in the Modified Clupicker to 39 and should reduce the assembly time by one half. A prototype of the Redesigned Clupicker was completed and tests were conducted using a large range of fabrics (including seven military fabrics) with varying physical properties. No adjustments were necessary to attain a total efficiency of 99.9% over the 1800 picks attempted.

This prototype has been sent back to Jet Sew for construction. In-plant production trials will be conducted and final engineering modifications will be implemented prior to commercialization.

Phase II (pending approval) will focus on production testing and evaluation as well as technology transfer. This information will be essential for rapid commercialization and industrial acceptance of the new fabric feeding device.

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Preface

This is the final report for the contract DLA-87-D-0017/0024 entitled, "Improvement of Clupicker Phase I" awarded by Clemson University under approval by the Defense Logistics Agency, prime contractor. The work presented within this report was supervised and conducted by Professor Ed McPherson, Dr. Timothy Clapp, and Mr. John Beaton from North Carolina State University in collaboration with Mr. Tony Aspland from Clemson Apparel Research and with Mr. Bob Beasock and Mr. Brion Dote from Jet Sew.

Executive Summary

The textile industry is very labor intensive, and attempts are being made to automate many operations. One of the major problems in automating these operations is finding a reliable method for ply separation-- picking the top piece of fabric from a stack of cut fabrics. There are many ply separation devices available today, but none of these devices are in common use. This is due to reliability and flexibility problems. In order to be economical, a ply separation device must correctly pick up only one piece of fabric at a time at least 995 times out of 1000. The ply separation device must also be flexible enough to sustain this reliability over a large range of fabric sizes and types with only simple, quick adjustments.

The Clupicker, a ply separation device made by Jet Sew that functions using a pinching action, is the most widely used pick-up device today. Performance testing has shown that the Clupicker can achieve a very high degree of mechanical efficiency ($\geq$99.5%) over a large range of fabrics. However, in order to reach these efficiency levels, the Clupicker must be properly adjusted for the fabric being used. This adjustment can be both difficult and time-consuming.

Previous research on the Clupicker included a survey of many of the companies that currently use the Clupicker and found that the existing Clupicker was not meeting all of the companies' needs. These requirements, determined from the survey results, included the following: a reduction in set-up and change over time, a reduction in the sensitivity to various fabrics, a reduction in the number of adjustments needed to change the range of fabric to be picked. The final result of this previous research was the Modified Clupicker which used an automatically adjusting gap setting to accommodate for a large range of fabrics. No adjustments were necessary for this picker to achieve an efficiency of 99.9% over a large range of fabrics.

Although the Modified Clupicker design did improve on the existing design, it still left much room for improvement in the areas of ease of manufacture and assembly. This design did not greatly reduce the number or complexity of the parts in the Clupicker. The goal of the redesign presented in this paper was to produce a new Clupicker design that would continue to perform at the high levels of efficiency achieved by the Modified Clupicker, while greatly improving its ease of manufacture and assembly. The redesign was based on the principles of Design for Assembly (DFA).

Design for Assembly techniques, if used properly, can result in great savings in production costs and increases in productivity. These methods, however, must be used in the early stages of the design process to gain their full benefits. There are several methods of analyzing the ease of assembly of a product, including Boothroyd's Systematic Design for Assembly Methodology and Zorowski's Product Design Merit for Ease of Assembly (PDM) computer program. These tools help to make the de-signer more aware of the effects of his design choices on the ease of assembly of a product.

The Redesigned Clupicker was designed based on the results of the systematic DFA analysis and the PDM analysis. This new design reduces the total number of parts from 80 in the Modified Clupicker to 39 and should reduce the assembly time by one half. A prototype of the Redesigned Clupicker was completed and tests were conducted using a large range of fabrics (including seven *military fabrics*) with varying physical properties. No adjustments were necessary to attain a total efficiency of 99.9% over the 1800 picks attempted.

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Chapter 1. Introduction

There are many ways to increase manufacturing productivity, but the one method that presents the greatest potential for significant reduction in production costs and increased productivity is the consideration of ease of manufacture and assembly during product design. If a product is poorly designed for manufacture and assembly, attempts can only be made to minimize the effects of this poor design. Improvement of the design or a complete redesign of the product would not be worth considering late in the process because of the time and money that have already been spent in producing the original design. Productivity can be meaningfully affected only when manufacturing and assembly techniques such as design for ease of manufacture and assembly are incorporated early in the design stage [4].

This paper describes the redesign of the Clupicker, a ply separation device used in the textiles industry. This redesign was undertaken in order to make the device easier to assemble and manufacture while meeting new technical requirements to satisfy customer demands. The redesign was based on the principles of Design for Assembly.

Chapter 2. Background

2.1 The Clupicker

The textile industry is very labor intensive, and attempts are being made to automate many operations. One of the major problems in automating these operations is finding a reliable method of picking the top piece of fabric from a stack of cut fabrics. Textile products, unlike other materials, are usually irregularly shaped, limp, and porous. All of these factors present problems when trying to grasp, separate, and orient a single ply of fabric [8].

Ply separation is a widely known problem in the textiles industry, and there are many ply separation devices available today, but none of these devices are in common use [17]. This is due to reliability and flexibility problems. In order to be economic, a ply separation device must correctly pick up only one piece of fabric at a time at least 995 times out of 1000-- a device with a reliability of only 90% operating at 20 parts per minute would require operator intervention twice per minute on average [17,19]. The ply separation device would also have to be flexible enough to sustain this reliability over a large range of fabric sizes and types with only simple, quick adjustments.

The Clupicker, a ply separation device that functions using a pinching action, is the most widely used pick-up device today [19]. It was originally developed by Cluett Peabody & Company Inc. and is now manufactured and distributed by its Jet Sew Corporation [10]. The instruction manual for the Clupicker claims that the Clupicker "is a simple device, both in design and operation... when properly adjusted, it is able to separate the top ply of material from a stack of material with an amazing degree of efficiency [7]." The Clupicker system is shown in Figure 2.1.

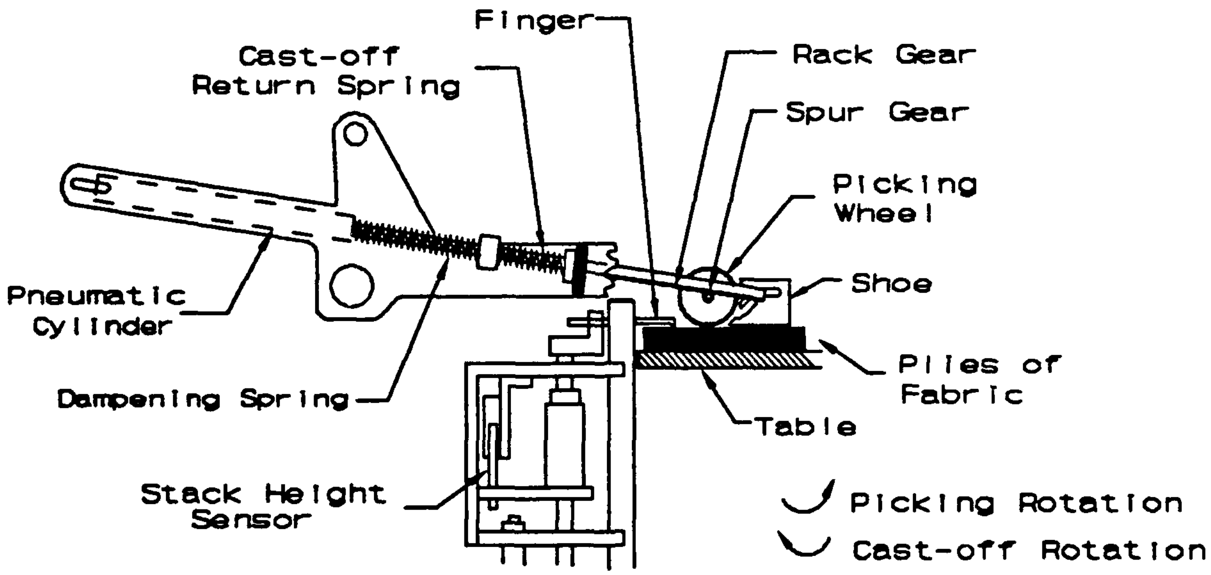


Figure 2.1 Clupicker system [8].

The Clupicker grasps a piece of fabric by using a pinching action. The picking wheel is placed on the fabric so the teeth penetrate the weave of the fabric. As the wheel rotates, the fabric is pinched between the wheel and the shoe. The wheel is rotated by a gear and rack system driven by a double acting pneumatic air cylinder. The fabric is released-- "casted off"-- when the air cylinder fires in the opposite direction. In order to ensure that the fabric has been completely released, the picking wheel rotates further during cast off than during the actual picking. Compression springs are used to return the picking wheel to its original position. The Clupicker system also includes a hold-down finger that acts to prevent the picking wheel from grasping more than one ply of fabric and to prevent the Clupicker from disturbing the rest of the stack [8].

Performance testing has shown that the Clupicker can achieve a very high degree of mechanical efficiency ($\geq$99.5%) over a large range of fabrics [16]. However, in order to reach these efficiency levels, the Clupicker must be properly adjusted for the fabric being used. This adjustment can be both difficult and time-consuming.

The Clupicker manual recommends adjusting only the pressure of the picking wheel against the top ply of fabric to account for any significant changes in the material properties. Thin, lightweight materials would require very light pressure; while heavier, thicker materials would require much more pressure. Brotherton and Tyler found that, by following these recommendations, the clupicker would perform very reliably [6]. However, finding the proper pressure setting for a particular fabric is largely a matter of "trial and error" [6].

In a separate performance study, Snyder and Clapp determined that the gap width-- the distance between the picking wheel and the shoe-- was the most critical adjustment for achieving optimum performance [16]. They found that the best performance was achieved when this gap width was set to the compressed thickness of two plies of the fabric to be picked. But this gap width is not easily adjusted by the operator, requiring the use of an Allen wrench and feeler gauge in a very compact space [16].

2.2 Results of Quality Function Deployment Analysis

Keith Daniel previously attempted a redesign of the Clupicker using Quality Function Deployment to evaluate and guide the design process [8]. Quality Function Deployment (QFD) is a system that allows the voice of the customer to be heard through each step of the design process. The first step in the QFD design process is determining the customer's desires and then translating these into technical requirements for the final product [9,18].

Daniel conducted a survey of many of the companies that currently use the Clupicker and found that the existing Clupicker was not meeting all of their needs [8]. The technical requirements determined from the survey results included the following [8]:

- have one set-up to cover a range of fabrics
- reduce sensitivity to various fabrics
- use modular components
- have one adjustment to change the range of fabric to be picked
- minimize set-up time
- possess the ability to pick from uneven stacks of fabric
- maintain stack quality
- maintain consistent force on fabric ply
- reduce number of parts

The end result of Daniel's work is the Modified Clupicker shown in Figure 2.2. This picker allows for a great deal of flexibility by using a self-adjusting gap setting that will accommodate the thickness of whatever material is being picked.

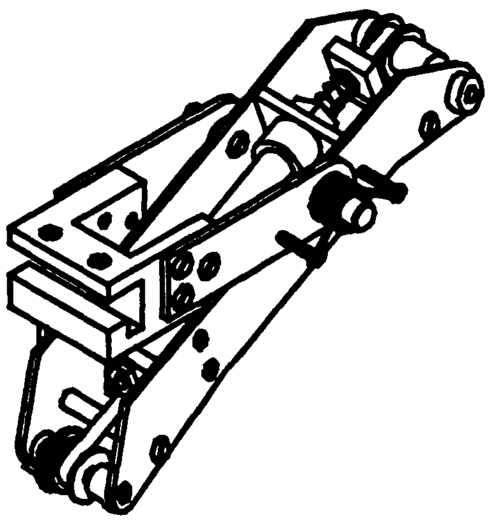


Figure 2.2 Modified Clupicker.

Like the original Clupicker, the Modified Clupicker also uses a pinching action to grasp the fabric ply. The picker is placed on the fabric so the teeth of the picking wheel penetrate the weave of the fabric. As the wheel rotates, the fabric is pinched between the wheel and the shoe. As the fabric is drawn in, the picking assembly pivots, adjusting the gap between the shoe and the picking wheel, allowing the fabric to be held. The wheel of this picker is rotated by a pulley and timing belt system driven by a double acting pneumatic air cylinder. Again, the fabric is casted off when the air cylinder fires in the opposite direction. This picker also rotates the picking wheel further during cast off than during the picking action to ensure that the fabric has been properly released. The compression springs are used to return the picking wheel to its original position. A torsion spring is used to apply the downward force on the picking assembly needed to successfully pick heavy, stiff fabrics.

This Modified Clupicker successfully addresses many of the technical requirements listed above. This design eliminates the need to adjust the Clupicker when different type of fabrics are picked. One set-up will cover the entire range of fabrics that it will pick. This also eliminates any set-up time. Some standardized parts were included in this design-- the pulleys and the timing belt are "off the shelf" items. The Modified Clupicker also applies a consistent force on the fabric ply with one spring rather than with the interaction between multiple springs used on the old Clupicker.

This Modified Clupicker was tested on a large range of fabrics (see Appendix A), and near-perfect levels of efficiency were achieved. The results of these tests are presented in Table 2.1. For six of the seven fabrics, the Modified Clupicker performed flawlessly. For the seventh fabric, a thick, stiff cloth, the picker missed two picks in the first 500 attempted picks. When the second 500 picks were attempted, the picker performed perfectly, missing no picks. These results give an average efficiency of 99.95% over 4000 picks with no adjustments required when changing fabrics.

Table 2.1 Military fabric test results for Modified Clupicker.

Fabric Number	Number of Picks	Missed Picks	Double Picks	Efficiency (%)
1	500	0	0	100
2	500	0	0	100
3	500	0	0	100
4	500	0	0	100
5	500	0	0	100
6	500	0	0	100
7	1000	2	0	99.8

In another test, a stack of assorted fabrics was used. The fabrics in this stack included wovens and nonwovens, and ranged from light-weight (2-3 oz./yard^2) to heavy (8-10 oz./yard^2) fabrics. A list of these fabrics can also be found in

Appendix A. The Modified Clupicker required no adjustments to successfully pick all of these fabrics. However, there were problems with fabrics 4, 5, and 6. Fabrics 4 and 6 are non-wovens and fabric 5 is a polyester-cotton mix with a stiff finish resulting in large ply-to-ply attraction forces between plies 4 and 5 and plies 5 and 6. The Modified Clupicker would double pick fabric 5 and either fabric 4 or 6. This situation would not normally occur in production.

2.3 Goal of this Redesign

Although the Modified Clupicker design did improve on the existing design, it still left much room for improvement in the areas of ease of manufacture and assembly. This design did not greatly reduce the number or complexity of the parts in the Clupicker. This subject will be more thoroughly addressed in the following chapters.

The goal of the redesign presented here was to produce a new Clupicker design that would continue to perform at the high levels of efficiency achieved by the Modified Clupicker while greatly improving its ease of manufacture and assembly. The redesign was based on the principles of Design for Assembly (DFA), Boothroyd's Systematic DFA Methodology, and Product Design Merit (PDM) software.

Chapter 3. Design for Assembly

3.1 Design for Assembly Guidelines

As a result of experience in applying Design for Assembly (DFA) techniques, Geoffrey Boothroyd of the University of Rhode Island has developed some general design guidelines that consolidate manufacturing knowledge and presents it to the designer as simple rules to be followed when developing a design. According to Boothroyd, assembly can be broken down into two separate processes: handling-- acquiring, orienting, and moving parts-- and insertion and fastening-- mating a part to another part or group of parts. The guidelines presented below cover both of these areas [4].

A. Design Guidelines for Part Handling

1. Parts should be designed with the maximum symmetry possible-- end-to-end and rotational symmetry about the axis of insertion. (see Figure 3.1a)
2. If symmetry is not possible, parts should be designed to be obviously asymmetric. (see Figure 3.1b)
3. Features should be provided so as to prevent the jamming of parts that may nest or stack when stored in bulk. (see Figure 3.1c)

4. Parts should be designed so as to avoid features that will allow tangling of parts when stored in bulk. (see Figure 3.1d)
5. Parts that are slippery, sticky, flexible, delicate, very large or very small, or that are hazardous to the handler (i.e. parts that are sharp, hot, etc.) should be avoided.

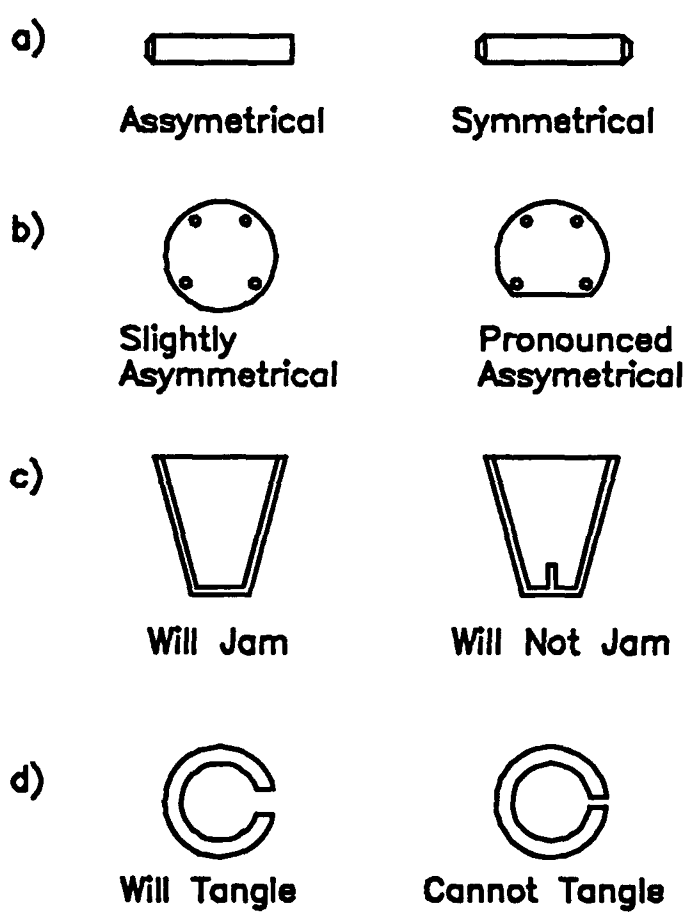


Figure 3.1 Geometrical features affecting part handling [4].

B. Design Guidelines for Insertion and Fastening

1. Parts should be designed to provide little or no resistance to insertion. Chamfers and generous clearances should be provided to guide insertion of mating parts. However, care must be taken to avoid clearances that will result in a tendency for parts to jam during insertion. (see Figure 3.2)

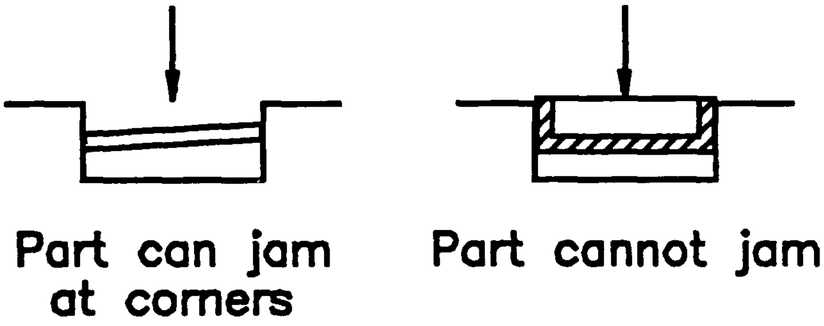


Figure 3.2 Poor design can allow jamming during insertion [4].

2. Use common parts, processes, and methods to standardize across all models and even across product lines in order to use higher-volume processes that normally result in lower product costs.
3. Assemble in layers about one axis-- assembly from above is preferred. (see Figure 3.3)

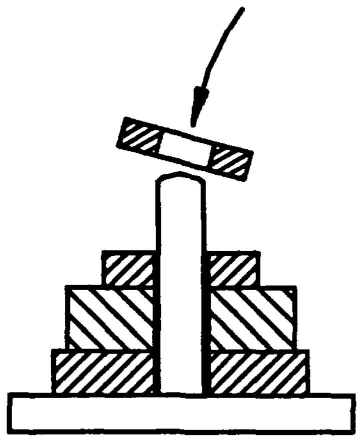


Figure 3.3 Assemble in layers about one axis [4].

4. Avoid the need to hold down parts after they have been added to the assembly. If this is not possible, design so the part is secured as soon as possible after its insertion.
5. Design parts to be located before they are released. Problems can occur if a part must be released before it has been positively located in the assembly. (see Figure 3.4)

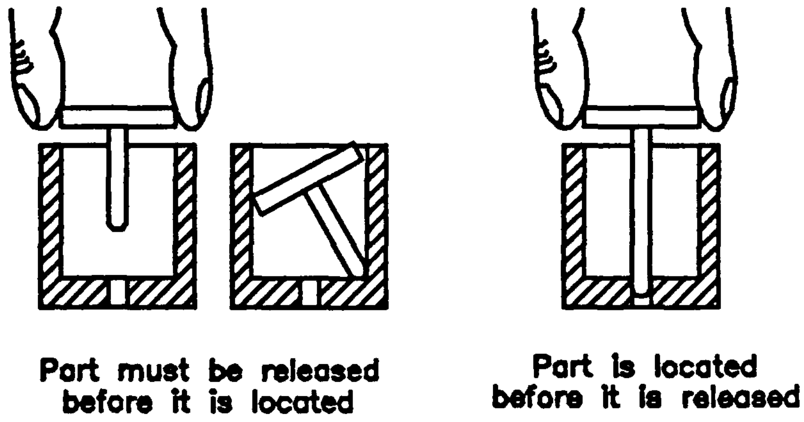


Figure 3.4 Design parts to be located before they are released [4].

6. If mechanical fasteners must be used, consider the relative cost of different fastening processes. The following processes are listed in order of increasing manual assembly cost:

   Snap fitting

   Plastic bending

   Riveting

   Screwing

7. Avoid having to reorient a partially completed assembly.

These guidelines are just a set of rules that provide the designer with suitable background information to use in developing a design that will be more easily assembled than a design developed without such a background. These guidelines alone are insufficient for a number of reasons. Guidelines provide no method of quantitatively evaluating a design for its ease of assembly. Also, there is no relative ranking of all the guidelines to indicate to the designer which guidelines will provide for the greatest improvements in handling and assembly. The designer would not know which guidelines to emphasize during the design of a product [4].

A method must be developed that would provide the designer with an organized method that incorporates the Boothroyd's guidelines and encourages the design of a product that is easy to assemble. This method must examine the handling and assembly features of one design and provide an estimate of how much easier it is to assemble than another design with different handling and assembly features. The "Product Design for Assembly" handbook written by Boothroyd and Dewhurst presents just such a method [3].

3.2 The Systematic DFA Methodology

Boothroyd and Dewhurst have developed a systematic methodology with which a designer can analyze a proposed design for ease of manual assembly. A classification and coding system for manual handling, insertion, and fastening processes based on experimental studies is used to estimate manual assembly times. These studies examined the effects of symmetry, size, weight, thickness, flexibility, and other factors on manual handling time. The effects of chamfers, part geometry, obstructed access, and restricted vision on manual insertion and fastening time were also explored. Boothroyd and Dewhurst's classification and coding system is presented in the form of two time standard systems-- one for handling and one for insertion and fastening [4].

3.2.1 Boothroyd's Classification System for Manual Handling

Boothroyd's classification system for manual handling is presented in Figure 3.5. This system takes into account a number of part features including size, thickness, weight, nesting, fragility, and flexibility. The classification code is made up of two digits. The first digit can be divided into four main groups [4]:

First Digit	Meaning
0 - 3	Parts of nominal size and weight that can be easily manipulated with one hand (without tools)
4 - 7	Parts requiring grasping tools because of their small size
8	Parts that may severely nest or tangle in bulk
9	Parts requiring two hands, two persons, or mechanical assistance in handling

ONE HAND

			PARTS ARE EASY TO GRASP AND MANIPULATE					PARTS PRESENT HANDLING DIFFICULTIES				
			THICKNESS > 2mm			THICKNESS ≤ 2mm		THICKNESS > 2mm			THICKNESS ≤ 2mm	
			SIZE > 15mm	6mm ≤ SIZE ≤ 15mm	SIZE < 6mm	SIZE > 6mm	SIZE ≤ 6mm	SIZE > 15mm	6mm ≤ SIZE ≤ 15mm	SIZE < 6mm	SIZE > 6mm	SIZE ≤ 6mm
			0	1	2	3	4	5	6	7	8	9
PARTS CAN BE GRASPED AND MANIPULATED BY ONE HAND WITHOUT THE AID OF GRASPING TOOLS	$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	$540° \le (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND WITH GRASPING AIDS

				PARTS NEED TWEEZERS FOR GRASPING AND MANIPULATION								PARTS NEED STANDARD TOOLS OTHER THAN TWEEZERS	PARTS NEED SPECIAL TOOLS FOR GRASPING AND MANIPULATION
				PARTS CAN BE MANIPULATED WITHOUT OPTICAL MAGNIFICATION				PARTS REQUIRE OPTICAL MAGNIFICATION FOR MANIPULATION					
				PARTS ARE EASY TO GRASP AND MANIPULATE		PARTS PRESENT HANDLING DIFFICULTIES		PARTS ARE EASY TO GRASP AND MANIPULATE		PARTS PRESENT HANDLING DIFFICULTIES			
				THICKNESS > 0.25mm	THICKNESS ≤ 0.25mm	THICKNESS > 0.25mm	THICKNESS ≤ 0.25mm	THICKNESS > 0.25mm	THICKNESS ≤ 0.25mm	THICKNESS > 0.25mm	THICKNESS ≤ 0.25mm		
				0	1	2	3	4	5	6	7	8	9
PARTS CAN BE GRASPED AND MANIPULATED BY ONE HAND BUT ONLY WITH THE USE OF GRASPING TOOLS	$\alpha \le 180°$	$0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
		$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
	$\alpha = 360°$	$0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
		$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS FOR MANIPULATION

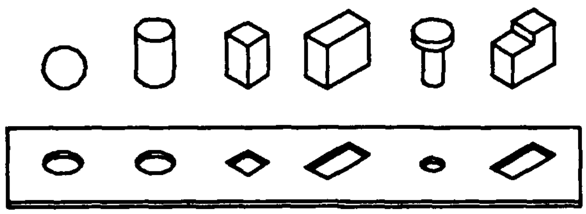
		PARTS PRESENT NO ADDITIONAL HANDLING DIFFICULTIES					PARTS PRESENT ADDITIONAL HANDLING DIFFICULTIES (E.G. STICKY, DELICATE, SLIPPERY, ETC.)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		SIZE > 15mm	6mm ≤ SIZE ≤ 15mm	SIZE < 6mm	SIZE > 6mm	SIZE ≤ 6mm	SIZE > 15mm	6mm ≤ SIZE ≤ 15mm	SIZE < 6mm	SIZE > 6mm	SIZE ≤ 6mm
		0	1	2	3	4	5	6	7	8	9
PARTS SEVERELY NEST OR TANGLE OR ARE FLEXIBLE BUT CAN BE GRASPED AND LIFTED BY ONE HAND (WITH THE USE OF GRASPING TOOLS IF NECESSARY)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS OR ASSISTANCE REQUIRED FOR LARGE SIZE

		PARTS CAN BE HANDLED BY ONE PERSON WITHOUT MECHANICAL ASSISTANCE									TWO PERSONS OR MECHANICAL ASSISTANCE REQUIRED FOR PARTS MANIPULATION
		PARTS DO NOT SEVERELY NEST OR TANGLE AND ARE NOT FLEXIBLE								PARTS SEVERELY NEST OR TANGLE OR ARE FLEXIBLE	
		PART WEIGHT < 10 lb				PARTS ARE HEAVY (> 10 lb)					
		PARTS ARE EASY TO GRASP AND MANIPULATE		PARTS PRESENT OTHER HANDLING DIFFICULTIES		PARTS ARE EASY TO GRASP AND MANIPULATE		PARTS PRESENT OTHER HANDLING DIFFICULTIES			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
TWO HANDS, TWO PERSONS OR MECHANICAL ASSISTANCE REQUIRED FOR GRASPING AND TRANSPORTING PARTS	9	2	3	2	3	3	4	4	5	7	9

Figure 3.5 Boothroyd's coding system for manual handling [3].

The codes for parts with first digits between 0 and 7, inclusive, are subdivided further based on the amount of orientation required due to symmetry. This symmetry can be divided into two categories-- alpha symmetry and beta symmetry. Alpha symmetry depends on the angle through which a part must be rotated about the axis perpendicular to the axis of insertion. Beta symmetry depends on the angle through which a part must be rotated about the axis of insertion. Examples of the symmetry of some simple parts can be seen in Figure 3.6 [21].



α	0	180	180	90	360	360
β	0	0	90	180	0	360

Figure 3.6 Examples of alpha and beta rotational symmetries for various parts [21].

The second digit of the handling code depends on the flexibility, stickiness, slipperiness, fragility, and nesting characteristics of the part. This digit is also dependent on the first digit [4]:

First Digit	Meaning of Second Digit
0 - 3	Size and thickness
4 - 7	Part thickness, type of tool required for handling of the part, and necessity for optical magnification
8	Size and symmetry
9	Symmetry, weight, and interlocking characteristics of parts in bulk

To demonstrate the use of Boothroyd's coding system for manual handling, the bearing of the right pivot arm side plate subassembly (Figure 3.7) of the Modified Clupicker will be used as an example. The insertion axis is vertical, and the part can

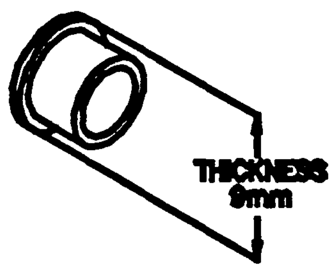


Figure 3.7 Bearing of right pivot arm side plate subassembly.

be oriented in any way along this axis; therefore the beta symmetry is 0 degrees. The part can be oriented only one way about the horizontal axis-- the alpha symmetry is 360 degrees. Thus, the total symmetry ($\alpha + \beta$) is 360 degrees. From Figure 3.5, for a part with a total symmetry of 360 degrees that can be grasped and manipulated with one hand, without the aid of tools, the first digit of the handling code is "1". Since the bearing can be easily grasped and manipulated, has a thickness of greater than 2 mm, and has a size between 6 mm and 15 mm, the second digit is "1", giving a handling code of "11". The handling time corresponding to this code is 1.8 seconds.

3.2.2 Boothroyd's Classification System for Manual Insertion and Fastening

Manual insertion and fastening covers several basic assembly tasks such as peg-in-hole assembly, screwing, and welding. The design features that affect insertion and fastening times include the accessibility of the assembly location, the ease of operation of any required assembly tools, the visibility of the assembly location, the ease of alignment and positioning during assembly, and the depth of insertion. This classification code, like the one for handling, is also made up of two digits. The first digit can be divided into three main groups [4]:

First Digit	Meaning
0 - 2	Parts not secured immediately after insertion
3 - 5	Parts that secure themselves or another part immediately after insertion
9	Processes involving parts already in place

The codes for parts with first digits between 0 and 5, inclusive, are subdivided further based on the effect of obstructed access and restricted vision [4].

The second digit is based on the first digit in the following manner [4]:

First Digit	Meaning of Second Digit
0 - 2	Ease of engagement of parts and if holding down is required to maintain orientation or location
3 - 5	Ease of engagement of parts and if the fastening operation involves a simple snap fit, screwing operation, or plastic deformation process
9	Mechanical, metallurgical, or chemical processes

Boothroyd's complete classification system for manual insertion and fastening is presented in Figure 3.8.

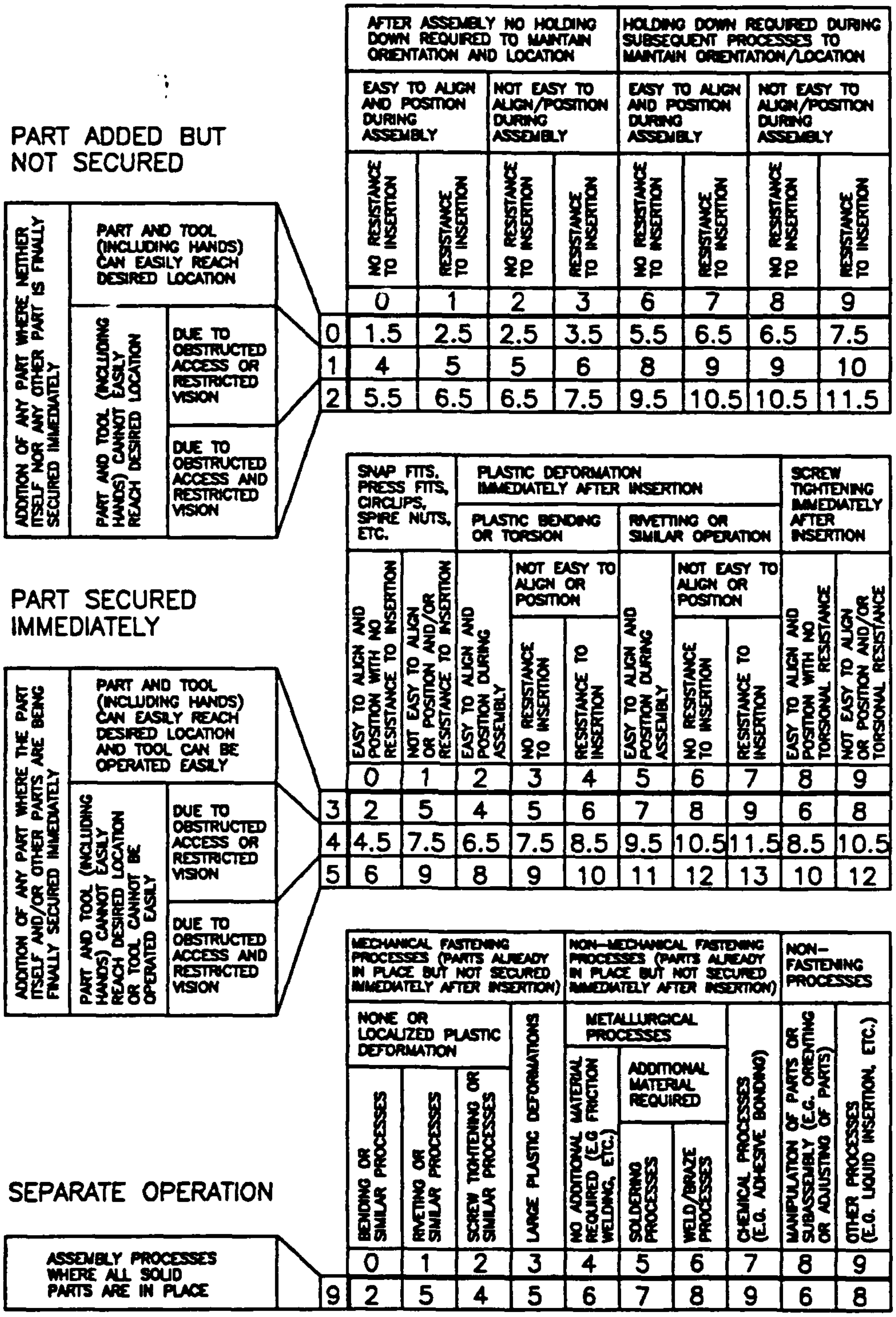


Figure 3.8 Boothroyd's coding system for manual insertion and fastening [3].

Again, the bearing of the right pivot arm side plate subassembly will be used as an example of Boothroyd's coding system for insertion and fastening. The bearing is secured immediately after insertion (it is press fit into the side plate), so, from Figure 3.8, the first digit of the insertion code will be "3" since the part can easily reach the desired location. Because the part is press fit and is easy to align and position, the second digit is "0", and the insertion code is "30". The insertion time corresponding to this code is 2 seconds.

3.2.3 Assembly Efficiency

An important element of this DFA methodology is the measurement of assembly efficiency. There are two main factors that affect the assembly cost of a product-- the total number of parts in the assembly and the ease of handling, insertion, and fastening. Boothroyd's "assembly efficiency" takes both of these into account. The assembly efficiency is determined by dividing the theoretical minimum assembly time by the estimated assembly time. The equation for the manual assembly efficiency, E_{ma}, is:

$$E_{ma} = N_{min}\, t_a \,/\, t_{ma} \tag{3.1}$$

N_{min} is the theoretical minimum number of parts, t_a is the basic assembly time for one piece, and t_{ma} is the estimated time to assemble the actual product [4].

The theoretical minimum number of parts is determined in the following manner. For each part in the assembly, the following three questions are asked [3]:

1. Must this part move relative to other parts in the assembly?
2. Must this part be made of a different material than other parts for functional reasons-- insulation, vibration damping, etc.-- not aesthetic reasons?
3. Must this part be made separate from other parts in order to permit other parts to be assembled?

If the answer to each of these three questions is "No", that part can be considered "redundant". The theoretical minimum number of parts is the total number of parts that are not considered redundant.

The basic assembly time for one piece, t_a, is the estimated time to handle, insert, and fasten an "ideal" part-- a part that presents no difficulties in handling, insertion, or fastening. Boothroyd assumes this time to be 3 seconds [3].

3.3 Product Design Merit for Ease of Assembly

The Product Design Merit (PDM) computer program developed by Zorowski and Warfford is a tool that can be used to evaluate the ease of automatic assembly of a design. Using PDM increases the designer's sensitivity to the impact of design decisions on the product's ease of assembly. PDM allows the designer to adopt a design methodology that is based on accepted principles of synthesis compatible with modern manufacturing technology. Finally, PDM provides a quantitative measure of the ease of automatic assembly as a basis for comparison of alternative designs or manufacturing options [22].

PDM is an interactive personal computer program that calculates a figure of merit for the ease of assembly of a part or product and checks each component for its possible elimination from the design. The PDM program asks the user to enter the name of each part in the design in the order it will be assembled. For each part, the user must determine and enter the following assembly parameters: insertion direction, fastening method, and feeding process. The answers given determine the parameter ratings which are then used to calculate a combined merit rating for the part. This merit rating will range from 0, the lowest, to 100, the highest [23].

The PDM analysis does not generate the amount of information that the DFA methodology does. It also does not give the designer an estimate of how long the assembly process will take or how much it will cost. What PDM does provide is a simple means of calculating a number that describes the general ease of assembly of the product that can then be used in comparison with other designs. The PDM analysis also indicates to the user which areas of the design need improvement. Subsequent analyses of a modified design can be performed to indicate any relative improvement over the initial design.

3.3.1 Insertion Direction

For each part, the first decision the designer must make is the insertion direction for the part. This direction must be chosen from a list of seven choices. These choices, listed in order from best to worst, are [23]:

1. Vertically from top
2. Horizontally from side
3. At an angle with horizontal
4. Combination of 1-3, above
5. 1, 2, or 3 plus a rotation
6. Combination of 1-3 plus a rotation
7. Vertically up from bottom

The program assigns a numerical value to each of these seven choices, with 100 going to the best choice (vertically from top) and 0 going to the worst choice (vertically up from bottom). The values for the choices in between are equally spaced over the range [24].

The user is then asked if the part must be held down prior to fastening. If the part does need to be held down, the value for the fastening direction choice is reduced by one half of a step [24].

3.3.2 Fastening Method

Next, the designer must choose the method that will be used to place and fasten the part into the assembly. Again, the user is given a list of possible choices. These choices, listed in order from best to worst, are [23]:

1. Slip or slide fit
2. Snap or light press fit
3. Clip or snap ring
4. Rivet or stake
5. Glue or adhesive
6. Screw
7. Nut and bolt
8. Press fit
9. Solder
10. Weld

Again, a numerical value is given to each of these ten choices, with 100 going to the best choice (slip or slide fit) and 0 going to the worst choice (weld). The values for the choices in between are equally spaced over the range [23].

3.3.3 Feeding Process

Then, the user has to choose the feeding process that will be used to deliver each part to the assembly. The designer is presented the following list from which to choose. The choices, listed in order from best to worst, are [23]:

1. Vibratory bowl feeder with easy part feeding and orientation
2. Vibratory bowl feeder with average difficulty part feeding and orientation
3. Vibratory bowl feeder with difficult part feeding and orientation
4. Precision pallet, slide tray, or magazine
5. Conveyor, standard pallet, or stacked container
6. Special handling (difficult to feed parts-- soft, sticky, flexible, etc.)
7. Manual handling

Once more, numerical values are given to each of these seven choices, with 100 going to the best choice (simple vibratory bowl) and 0 going to the worst choice (manual handling). The values for the choices in between are, again, equally spaced over the range [23].

3.3.4 Part Redundancy Check

Finally, the PDM program asks the user to answer three additional questions about each part in order to determine if that part is redundant and could be considered for elimination [24]. These three questions are the same as those used by Boothroyd:

1. Does the part move relative to parts already assembled in the normal function of the final assembly?
2. Must the part be made of a different material from parts already assembled for functional (not aesthetic) reasons?
3. Must the part be separate from parts already assembled to permit necessary assembly or disassembly?

PDM also reminds the user that fasteners are rarely counted as essential separate parts. If the user answers "No" to all three of these questions, that part is labelled redundant and should be considered for elimination [24].

3.3.5 Merit Values

PDM models the "Combined Merit" of each part as the length of a vector in three dimensional space. The three components of the vector are the values of the ease of insertion, ease of fastening, and the ease of feeding ratings. If the combined merit falls inside a sphere whose radius is equal to the maximum value of any one assembly parameter, the combined merit for the part is taken to be zero. This would be equivalent to at least two of the parameters having their lowest value. The combined merit of each part is normalized to give a maximum value of 100 [23]. Figures 3.9 and 3.10 show how each of the merit value components are related.

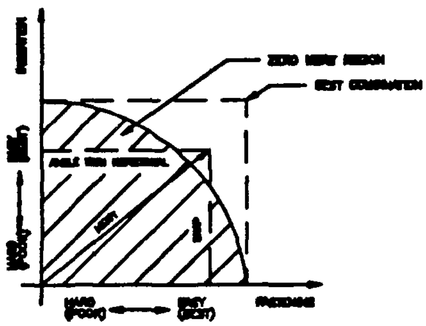


Figure 3.9 Two dimensional model for part inserted at an angle with horizontal, fastened with snap fit [24].

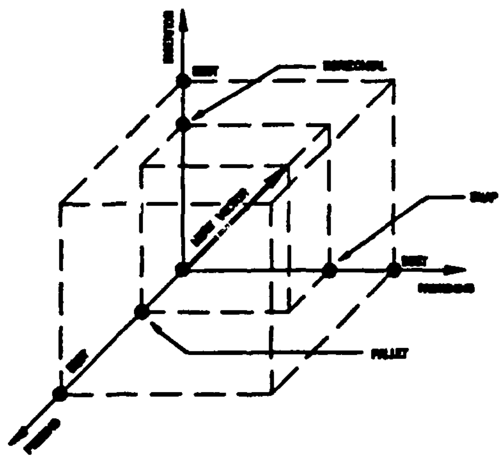


Figure 3.10 Three dimensional model for part inserted horizontally, fastened with snap fit, fed by pallet [24].

The "Average Combined Merit" for the entire assembly is the average of all of the combined merit values for each piece in the assembly. The "Assembly Merit" takes into consideration the average combined merit, the number of parts in the assembly, and the number of redundant parts. The Assembly Merit is derived from the following equation [24]:

$$AM = ACM * (1 - RP/TP) \qquad (3.2)$$

where AM is the assembly merit, ACM is the average combined merit, RP is the number of redundant parts, and TP is the total number of parts in the assembly. For example, if an assembly containing ten parts (two redundant) had an Average Combined Merit of 90, the Assembly Merit would be calculated as follows:

$$\begin{aligned} AM &= 90 * (1 - 2/10) \\ &= 72 \end{aligned}$$

After the initial analysis using PDM, the designer can examine the results to determine where improvements can be made. If the average combined merit were much greater than the assembly merit, the designer would most likely need to eliminate redundant parts. If the values of the assembly merit and the average combined merit were very close, improvement would need to be made in the feeding, insertion, or fastening of the existing parts. In some cases, it may be possible for the designer to raise the assembly merit while lowering the average combined merit.

This may seem illogical, but it can be done. For example, if the designer eliminates redundant parts by combining them with others, the resulting parts may become more difficult to feed, insert, or fasten. Thus, the combined merit values for the existing pieces may be lowered while the assembly merit of the whole product would be improved due to the elimination of redundant parts.

Chapter 4. The Clupicker Design

4.1 The Modified Clupicker Design

The Modified Clupicker is shown again in Figure 4.1.

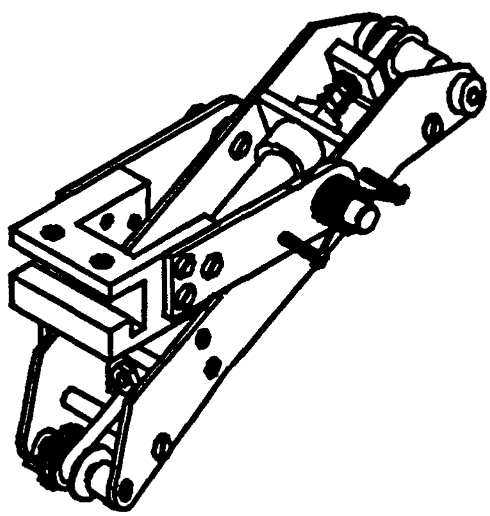


Figure 4.1 The Modified Clupicker.

The assembly of the Modified Clupicker can be broken down into ten subassemblies. Each subassembly is presented below.

The side plate subassembly (Figure 4.2) starts with a hub (1) welded to a side plate (2). Then, a bearing (3) is press fit into the side plate. Next, the pivot pin (4) is held onto the side plate and the subassembly is turned over. The pivot pin is then fastened with a screw (5). There are two side plate subassemblies.

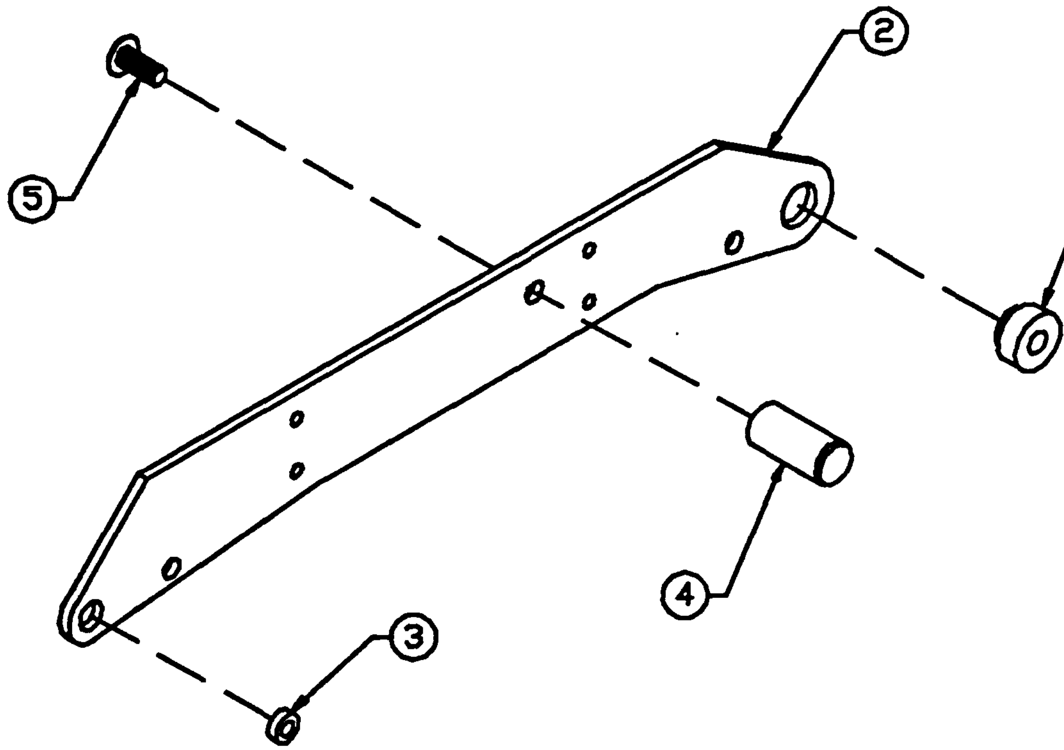


Figure 4.2 Side plate subassembly.

The cylinder subassembly (Figure 4.3) starts with the double acting pneumatic cylinder (6). A cylinder mounting block (7) is inserted over each end of the cylinder rod. Nuts (8) are then used to hold these blocks in place. A spring (9) and a rod-end/belt-clamp block (10) are then inserted over each end of the cylinder rod. A nut (11) holds each of these blocks in place. The timing belt (12) is then positioned and held on the rod-end/belt-clamp blocks. Two screws (13) secure each belt clamp (14).

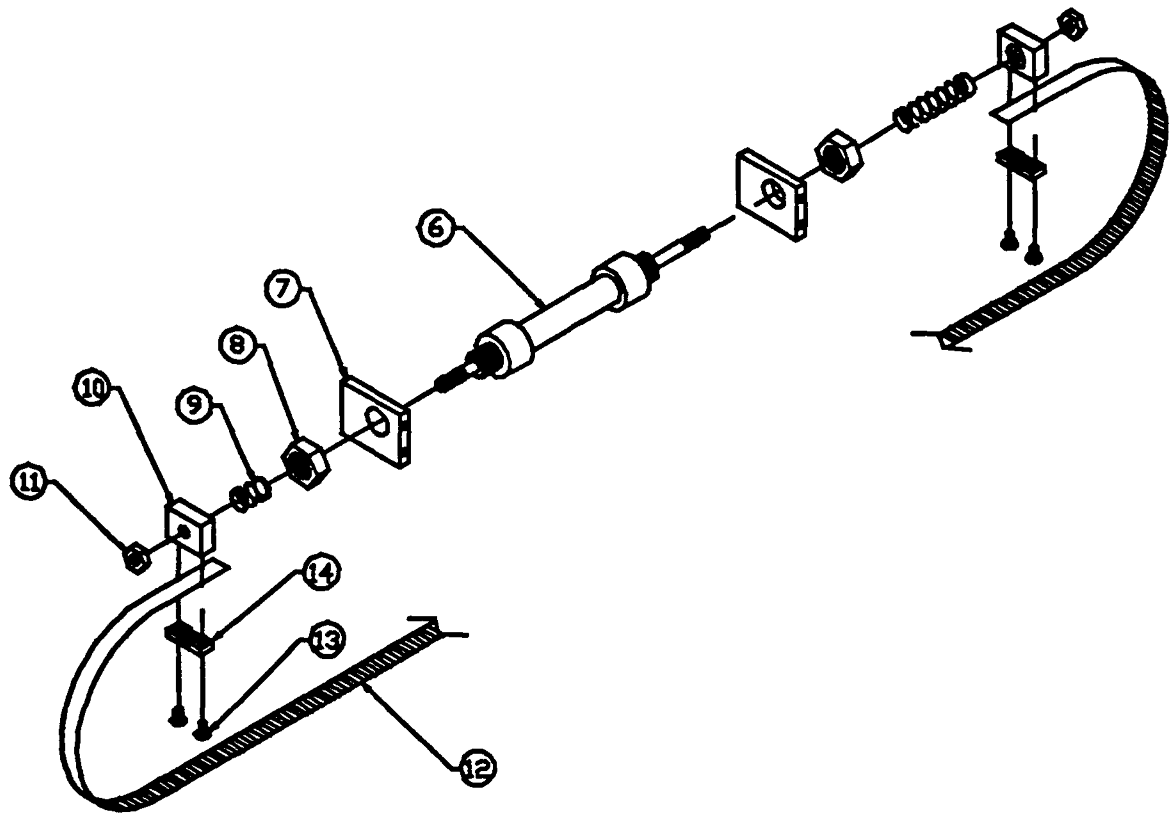


Figure 4.3 Cylinder subassembly.

The back pulley subassembly (Figure 4.4) consists of a shaft (15) with the pivot end pulley (16) and two spacers (17,18) inserted on it.

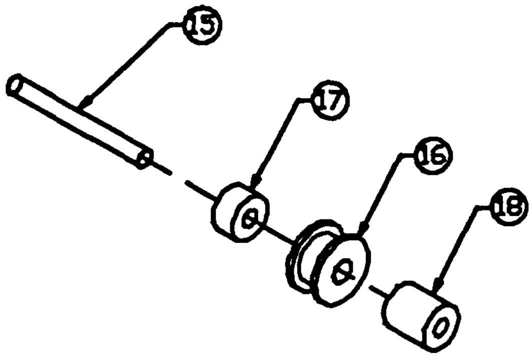


Figure 4.4 Back pulley subassembly.

The pick wheel hub subassembly (Figure 4.5) is made up of the pick wheel shaft (19) with the pick wheel hub (20) press fit onto it.

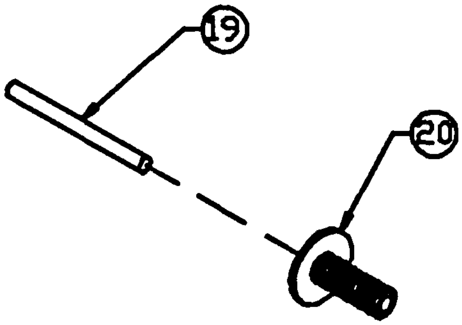


Figure 4.5 Pick wheel hub subassembly.

This pick wheel hub subassembly (21) is then used to start the pick wheel subassembly (Figure 4.6). A spacer (22) is inserted over one end of the shaft. Five pick wheel spacers (23) and four picking wheel blades (24) are alternately inserted over the hub subassembly shaft. Two shims (25,26) are inserted, and the pick wheel pulley (27) is screwed onto the hub. Another spacer (28) finishes this subassembly.

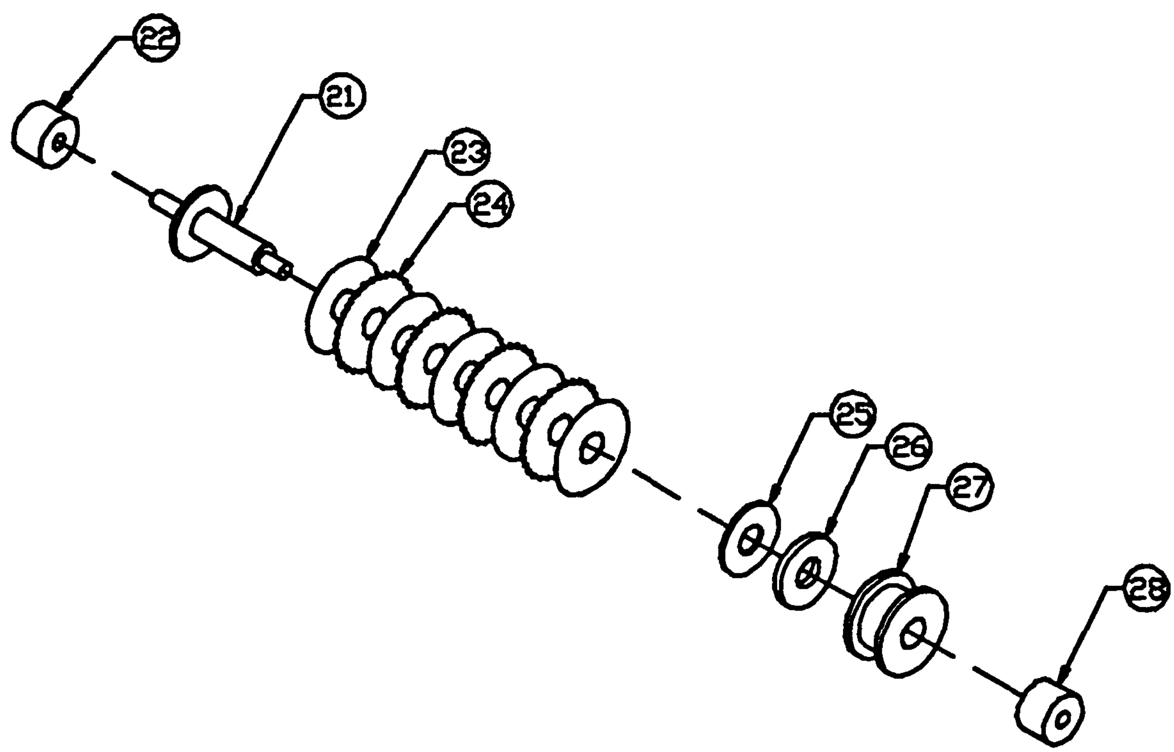


Figure 4.6 Pick wheel subassembly.

A bearing (29) is press fit into the right pivot arm plate (30). The pin rest (31) is then held in place while the pivot arm plate is turned over. A screw (32) fastens the pin rest. This is the right pivot arm side plate subassembly (Figure 4.7).

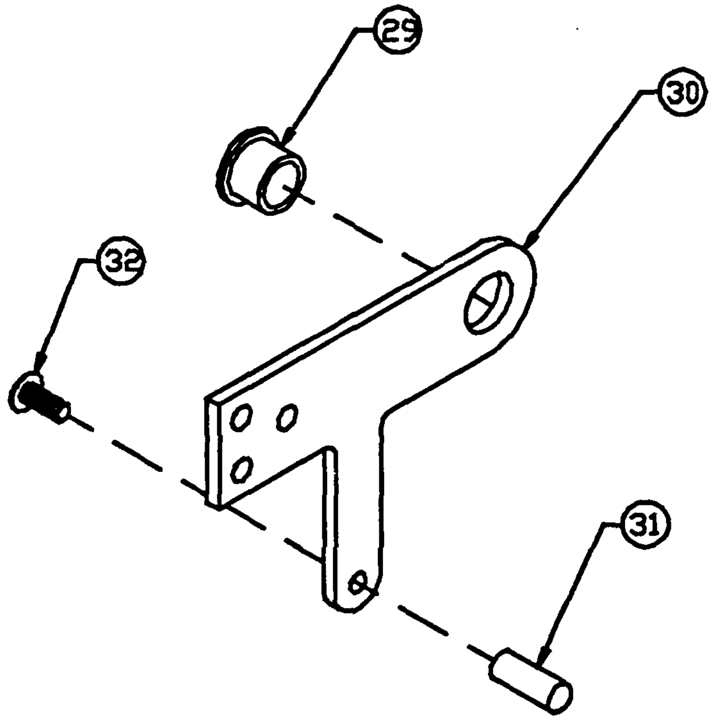


Figure 4.7 Right pivot arm side plate subassembly.

This right pivot arm plate subassembly (33) is attached to the pivot arm block (34) with three screws (35) to begin the mounting block subassembly (Figure 4.8). The partially-completed subassembly is rotated, and the knurled shoe (36) is then added and fastened with two screws (37).

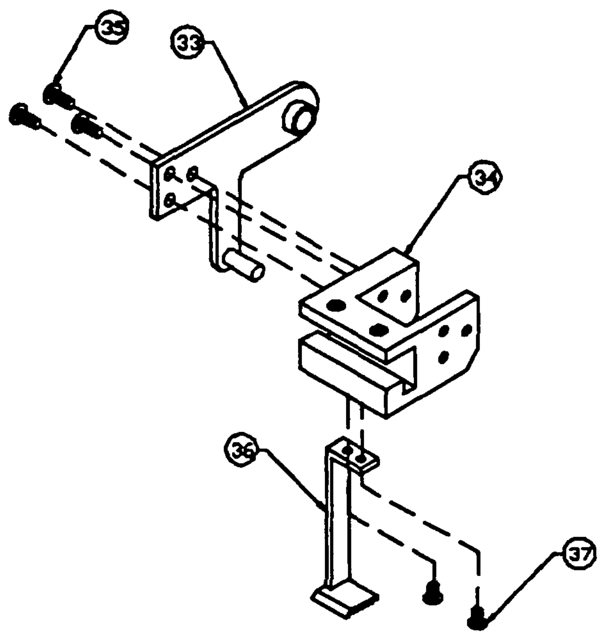


Figure 4.8 Mounting block subassembly.

The pivoting subassembly (Figure 4.9) begins with a side plate subassembly (38) being placed on the cylinder subassembly (39). The cylinder subassembly is held down while it is fastened with four screws (40). This partially-completed subassembly is then turned over. The shaft of the back pulley subassembly (41) is inserted into the hub of the side plate, and the shaft of the pick wheel subassembly (42) is inserted into the bearing of the side plate. The two side plate supports (43) are added and held in place while the second side plate subassembly (44) is added. One screw

(45) fastens each of the side plate supports, two screws (46) fasten each mounting block of the cylinder subassembly. One of these mounting block screws (47) is longer and acts as a spring pin. The whole subassembly is turned over again, and two more screws (48) are added to fasten the side plate supports.

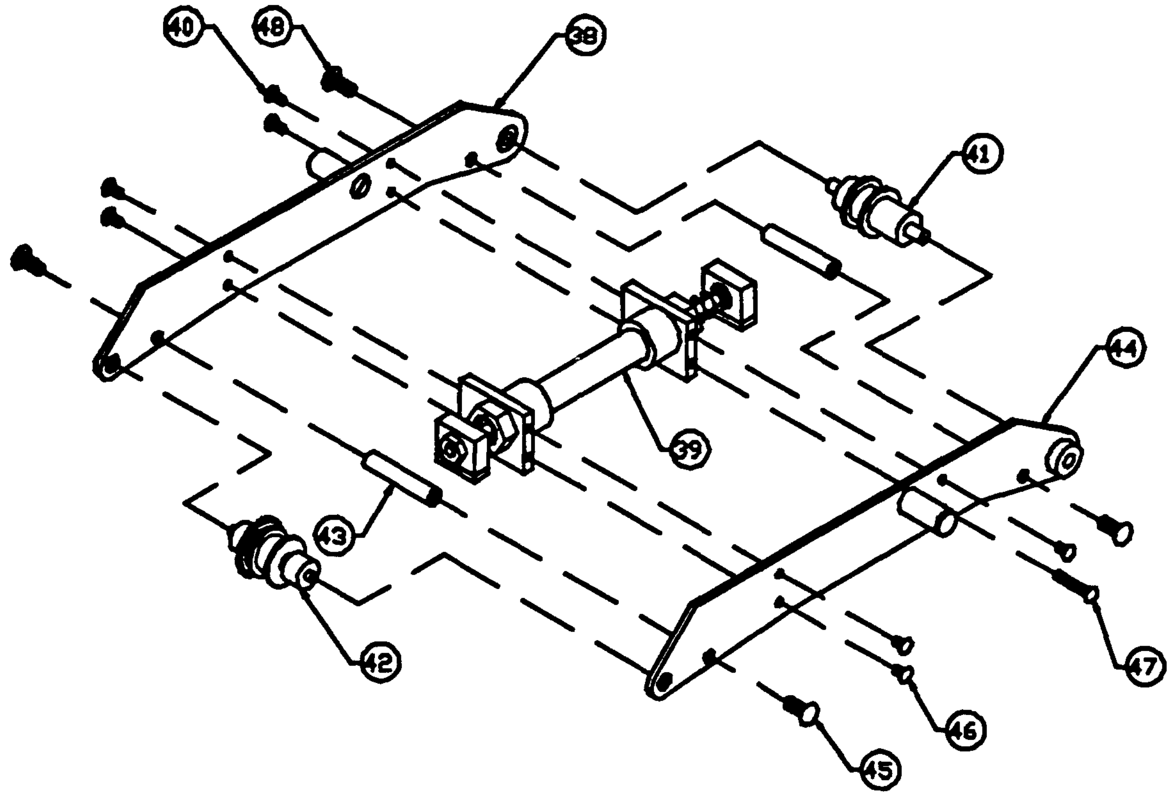


Figure 4.9 Pivoting subassembly (timing belt removed).

A bearing (49) is press fit into the left pivot arm side plate (50), and the spring pin screw (51) is attached. This is the left pivot arm subassembly (Figure 4.10).

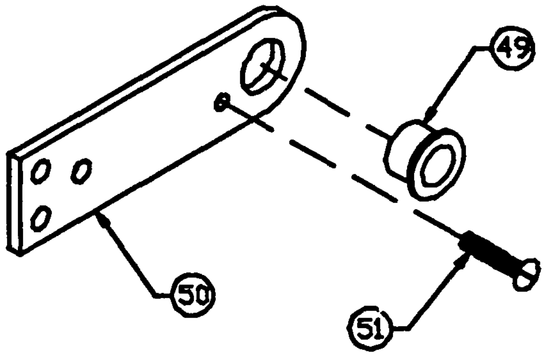


Figure 4.10 Left pivot arm subassembly.

The pivot pin of the pivoting subassembly (52) is inserted into the mounting block subassembly bearing (53), and the bearing of the left pivot arm side plate (54) is inserted over the second pivot pin. The left pivot arm side plate in then attached with three screws (55). The assembly of the Modified Clupicker (Figure 4.11) is completed when a torsion spring (56) is attached to the pivoting subassembly and the mounting block subassembly around the pivot pin.

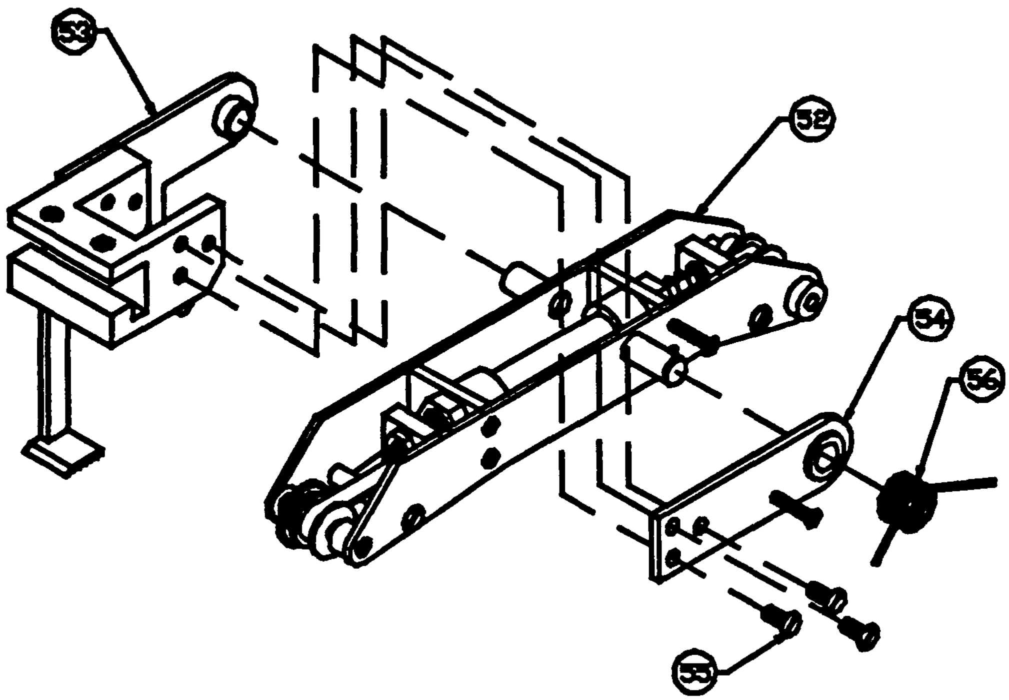


Figure 4.11 Modified Clupicker-- Final assembly.

4.1.1 The Modified Clupicker-- DFA Methodology Analysis

An analysis of the Modified Clupicker using Boothroyd's systematic DFA methodology was completed. This analysis was conducted on each subassembly-- when a subassembly appeared as a part in another subassembly, it was treated as a separate part. The results for the side plate subassembly can be seen in Table 4.1.

The cost of manual assembly is dependent upon the burdened rate of the assembly worker. This rate includes overheads and was assumed to be $30 per hour (0.83 cents/second) [4]. The cost of each operation and the total assembly cost for each subassembly were calculated. The assembly efficiency was calculated for each subassembly as well as for the entire Modified Clupicker assembly.

The side plate subassembly is made up of five parts, but only one of these parts-- the side plate-- is not redundant. This part is not considered redundant because it is the base part for this subassembly. Each of the other parts could conceivably be combined with the side plate. None of these parts move, they do not have to be made of different materials, and they do not have to be separate parts to allow the assembly of other parts. This subassembly involves a reorientation-- it must be turned over to allow for the pivot pin screw to be secured-- resulting in a time delay of 9 seconds. The total time for this assembly is 46.33 seconds resulting in an assembly cost of 38.45 cents. The assembly efficiency for this subassembly can be calculated using equation 3.1 as follows:

$$E_{ma} = N_{min}\, t_a / t_{ma}$$
$$= (1)(3)/(46.33)$$
$$= 0.06 \text{ or } 6\%$$

Table 4.1 DFA Analysis-- Side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Side Plate Hub	1	11	1.80	96	12.00	13.80	11.45	0
Wheel Shaft Bearing	1	09	2.98	30	2.00	4.98	4.13	0
Pivot Pin	1	11	1.80	06	5.50	7.30	6.06	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Screw (Pivot Pin)	1	11	1.80	38	6.00	7.80	6.47	0
						46.33	38.45	

Where:
- RP= Number of items
- HC= Handling code
- TH= Handling time per item
- IC= Insertion code
- TI= Insertion time per item
- TA= Total operation time (RP*(TH+TI))
- CA= Total operation cost
- NM= Figure for minimum number of parts (= 0 if part is redundant) (= 1 if part not redundant)

The full analysis using the DFA methodology can be found in Appendix B.

A summary of these results is presented in Table 4.2.

Table 4.2 Modified Clupicker-- DFA analysis.

Subassembly	No.	Assembly Time (seconds)	Assembly Efficiency (%)
Side Plate	2	46.33	6
Cylinder	1	124.04	15
Back Pulley	1	11.12	60
Pick Wheel Hub	1	6.13	49
Pick Wheel	1	51.53	6
Right Pivot Arm Side Plate	1	31.35	10
Mounting Block	1	66.35	5
Pivoting	1	107.91	11
Left Pivot Arm	1	7.25	41
Modified Clupicker	1	55.20	22
Total Time:		553.54	

The cylinder subassembly contains 18 parts, 12 of which are redundant. The air cylinder is not redundant-- it acts as the base part for this subassembly. The two springs must be separate parts to allow for the motion of the cylinder rod. The timing belt must be made of a different material, so it is not redundant. The two belt clamps are also not redundant-- they must be separate to allow for the assembly of the timing belt. This subassembly will require a total of 124.04 seconds-- a cost of 102.95 cents. The assembly efficiency was calculated to be 15%.

The back pulley subassembly consists of two redundant parts and two non-redundant parts. The two spacers could be combined with the pivot end pulley, but the pulley itself moves with respect to the pivot end shaft. The shaft is not considered redundant because it is the base part for this subassembly. The total time to assemble the back pulley subassembly is 11.12 seconds, the total cost is 9.29 cents, and the assembly efficiency is 60%.

The two parts of the pick wheel hub subassembly could be combined into one part. The pick wheel shaft is the base part and is not redundant, but the hub is redundant. It is estimated that the time to produce this subassembly will be 6.13 seconds-- a cost of 5.09 cents. The assembly efficiency was calculated to be 49%.

This pick wheel hub subassembly then becomes the only non-redundant part in the pick wheel subassembly. Each of the 14 other parts could be combined with the pick wheel hub subassembly to make only one part. The time required for this subassembly is 51.53 seconds, and the cost is 42.77 cents. The assembly efficiency is 6%.

The right pivot arm side plate subassembly consists of four parts. The right pivot arm side plate is not redundant-- it is the base part for this subassembly. The other parts could possibly be combined with the side plate to make a single part. This subassembly must be turned over to allow for the pin rest screw to be secured. This reorientation results in a time delay of 9 seconds. The total time to produce this subassembly is 31.35 seconds. The cost is 26.02 cents. For this subassembly, the assembly efficiency is 10%.

This right pivot arm side plate subassembly is then used in the mounting block subassembly. The base part-- the pivot arm block-- is the only non-redundant part. The other parts in this subassembly do not satisfy any of the requirements needed to be considered non-redundant and could be made as one part. This subassembly also requires a reorientation. The total assembly time is 86.35 seconds, the cost is 55.07 cents, and the assembly efficiency is 5%.

The cylinder subassembly serves as the base component for the pivoting subassembly and is not redundant. The back pulley subassembly and the pick wheel subassembly both move with respect to the two side plate subassemblies and cannot be considered redundant. The second side plate subassembly must be a separate part to allow for the assembly of many parts, including the pick wheel and back pulley subassemblies. Each of the other parts is redundant. This assembly can be produced in an estimated 107.91 seconds and will cost 89.57 cents. The assembly efficiency is 11%.

The left pivot arm side plate consists of three parts, two of which are redundant. The bearing and the spring pin screw could be combined with the base part, the left pivot arm side plate. The total assembly time is 7.25 seconds, resulting in a cost of 6.02 cents. The assembly efficiency was calculated to be 41%.

The final assembly of the Modified Clupicker begins with the base part-- the mounting block subassembly. The pivoting subassembly must be free to move, so it is not redundant. The left pivot arm side plate subassembly is not redundant because it must be a separate part to allow the pivoting subassembly to be inserted. The torsion spring must also be a separate part. The only redundant parts in this assembly are the three screws used to secure the left pivot arm side plate assembly. The time required for this assembly is 55.2 seconds-- a cost of 45.8 cents. The assembly efficiency is 22%.

The total time to assemble the 80 parts that make up the entire Modified Clupicker is 553.54 seconds (9 minutes and 13 seconds), and the assembly cost is $4.59. The average of all of the assembly efficiencies of the subassemblies is 20%. The overall assembly efficiency, calculated using the total number of non-redundant parts (23) and the total assembly time, is 12.5%.

4.1.2 The Modified Clupicker-- PDM Analysis

An analysis of the Modified Clupicker was also conducted using PDM. As before, the analysis was conducted separately on each subassembly; and, when a subassembly appeared as a part in another subassembly, it was treated as a separate part.

The PDM analysis results for the side plate subassembly are presented in Table 4.3. This table is a portion of the output provided by PDM and shows the user's choices of the insertion direction, hold down needs, fastening method, and feeding method, as well as the result of redundancy check for each part. The merit scores associated with each of these choices are also provided. For this assembly the combined average merit is 86, and the assembly merit is 17. The great difference between these two merits is due to the large percentage of redundant parts in this subassembly-- 4 of the 5 parts are redundant. The complete PDM analysis results for each subassembly in the Modified Clupicker can be found in Appendix C.

Table 4.3. PDM analysis-- Side plate subassembly.

PART INPUT DATA

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Side Plate	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Side Plate Hub	VERT DOWN	Y	WELD	VIB BOWL	YES
3	Wheel Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
4	Pivot Pin	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
5	Screw (Pivot)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Side Plate	100	100	50	87	NO
2	Side Plate Hub	92	0	100	78	YES
3	Wheel Bearing	100	22	100	83	YES
4	Pivot Pin	92	100	100	97	YES
5	Screw (Pivot)	100	44	100	86	YES

AVG COMBINED MERIT: 86 ASSEMBLY MERIT: 17

The average combined merit (ACM) and the assembly merit (AM) were calculated for each subassembly. The averages of the merits were also calculated. These results are listed in Table 4.4.

Table 4.4 Merit values from PDM analysis.

No.	Subassembly	Qty	ACM	AM
1	Side Plate	2	86	17
2	Cylinder	1	85	28
3	Back Pulley	1	99	50
4	Pick Wheel Hub	1	96	48
5	Pick Wheel	1	95	6
6	Right Pivot Arm Side Plate	1	88	22
7	Mounting Block	1	86	11
8	Pivoting	1	83	17
9	Left Pivot Arm Side Plate	1	84	28
10	Modified Clupicker	1	82	47
Averages:			88	26

4.2 Discussion of Results and Design Recommendations

It is clear from examining the Modified Clupicker that this design does not follow many of the design for assembly guidelines presented above. There are many external fasteners-- the design contains 28 screws. Many parts must be held down before they are fastened. There are flexible items, such as the timing belt. Many parts are very difficult to orient and fasten. Several reorientations are necessary throughout the assembly process. Both the DFA methodology analysis and the PDM analysis also show that this design does not follow many of the design for assembly guidelines presented above.

Using the DFA methodology, the overall assembly efficiency is 12%. This is a relatively low value due partially to the large number of redundant parts present. Another reason for this low value is the presence of so many screws. In a majority of the subassemblies, screw handling and fastening require the single largest amount of time. The subassemblies that require the most time to assemble are the cylinder subassembly (124.04 seconds), the pivoting subassembly (107.91 seconds), and the two side plate subassemblies (92.66 seconds total).

From the PDM analysis, the average of the Average Combined Merits is a relatively high 88, but the average Assembly Merit is only 26. This great difference between the two merits indicates that there are a large number of redundant parts in the

Modified Clupicker assembly. The worst subassemblies in terms of Assembly Merit are the pick wheel subassembly (6), the mounting block subassembly (11), the pivoting subassembly (17), and the side plate subassembly (17).

Based on both of these analytical methods, the subassemblies that need the most improvement are:

1. Cylinder subassembly
2. Pivoting subassembly
3. Side plate subassemblies
4. Pick wheel subassembly
5. Mounting block subassembly

Also, both of these analyses indicate that the greatest possibility for improvement lies in the elimination of redundant parts.

4.3 The Redesigned Clupicker

Based on the results of the DFA methodology analysis and the PDM analysis, the Modified Clupicker was redesigned. The product of this new design effort is the Redesigned Clupicker (Figure 4.12) that uses a smaller, single acting air cylinder to drive a link attached to the pick wheel assembly. The use of this smaller air cylinder allows for a great reduction in the overall size and complexity of the design. The reduction in size can be seen in Figure 4.13.

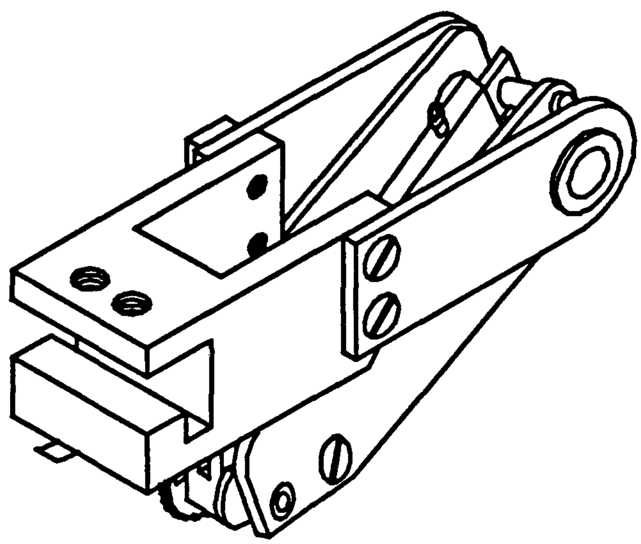


Figure 4.12 Redesigned Clupicker.

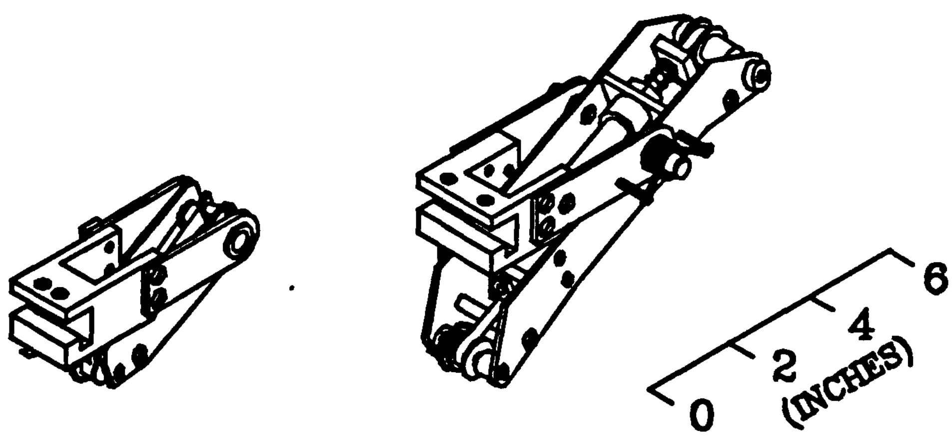


Figure 4.13 Size comparison-- Redesigned Clupicker vs. Modified Clupicker.

Each of the two redesigned side plate assemblies (Figure 4.14) consists of three parts. First, a bearing (1) is press fit into the side plate (2). Next, the pivot pin (3) is press fit into the side plate. In the previous design, this pivot pin was fastened using a screw, and a reorientation was required to secure the screw. The elimination of the screw, a redundant part, will improve the PDM Assembly Merit as well as reduce the assembly time estimated with the DFA methodology analysis.

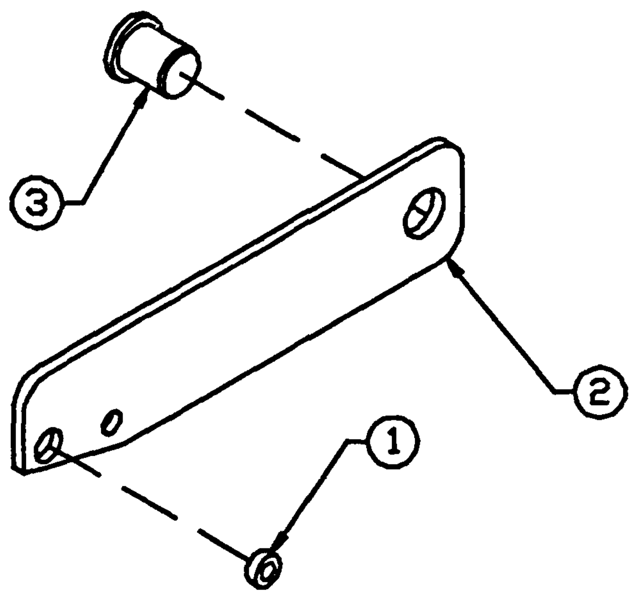


Figure 4.14 Redesigned side plate subassembly.

The pick wheel hub subassembly (Figure 4.15) is made up of the pick wheel shaft (4) with the pick wheel hub (5) press fit onto it. The hub could possibly be combined with the shaft to make only one part, but this subassembly was not changed. Manufacturing the pick wheel hub subassembly as one part would be more difficult than assembling the two pieces.

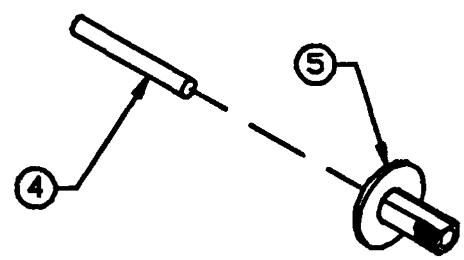


Figure 4.15 Redesigned pick wheel hub subassembly.

This hub subassembly (6) is then used in the new pick wheel subassembly (Figure 4.16). Five pick wheel spacers (7) and four picking wheel blades (8) are alternately inserted over the hub subassembly shaft. The driven link (9) is inserted onto the hub, and then the pick wheel nut (10) is screwed onto the hub, securing the whole assembly. This new subassembly differs from the previous one in that two spacers and two shims are eliminated. Also, the driven link replaces the pick wheel pulley used in the Modified Clupicker. The ease of assembly of this was not greatly improved, but these changes were made to allow the use of a new drive system. Greater improvements could be made by producing the pick wheel as one part rather than the nine parts used now.

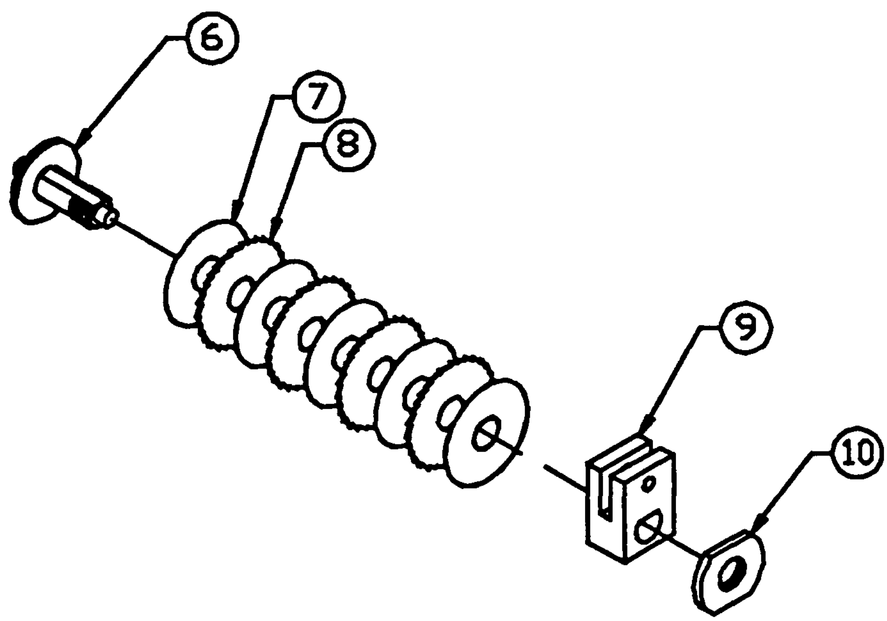


Figure 4.16 Redesigned pick wheel subassembly.

The Redesigned Clupicker, as mentioned above, uses a different drive system. This drive subassembly (Figure 4.17) replaces the cylinder subassembly including the timing belt as well as the two pulleys in the Modified Clupicker. The new drive subassembly starts with the small pneumatic cylinder (11). The pick wheel subassembly (12) is attached with the connecting pin. A retaining ring (14) fastens the pin. This new subassembly uses far fewer parts than the old cylinder subassembly, and it should be much easier and require less time to assemble. The new drive subassembly does not, however, provide for the additional cast-off motion in the Modified Clupicker. Tests conducted using the Modified Clupicker with its cast-off ability disabled showed that this extra rotation of the pick wheel was not required to properly release the fabric.

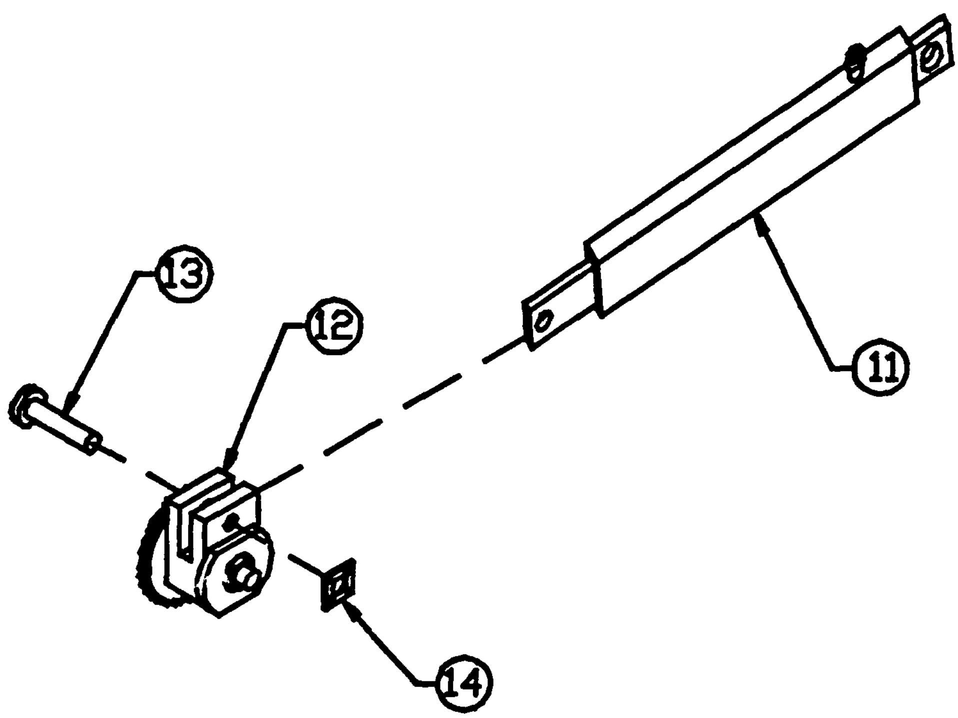


Figure 4.17 Drive subassembly.

A bearing (15) press fit into each of the two pivot arm side plates (16) completes the pivot arm side plate subassemblies (Figure 4.18). In the previous design, there were two different pivot arm side plates-- one for the left side and one for the right side. The use of standard parts will increase the ease of assembly. The Modified Clupicker also had a pin rest on the right pivot arm side plate that served to prevent the pick wheel on the pivoting subassembly from contacting the shoe. However, it was found through experimentation that the gap caused by the pin rest would adversely effect the performance of the Modified Clupicker. The Redesigned Clupicker has no pin rest.

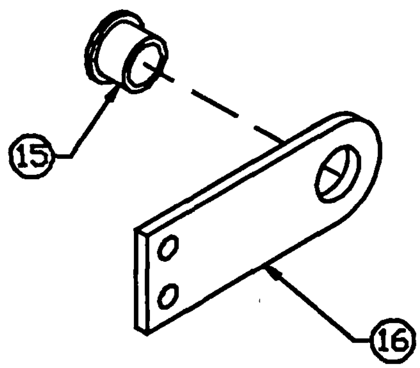


Figure 4.18 Redesigned side plate subassembly.

The redesigned mounting block subassembly (Figure 4.19) is similar to the previous one. One pivot arm side plate subassembly (17) and the shoe (18) are placed on the pivot arm block (19). Two screws (20) hold the side plate and shoe. The subassembly is then rotated, and the leaf spring (21) is then added and fastened with a screw (22). In the Modified Clupicker mounting block subassembly, the side plate and the shoe were attached to the pivot arm block in separate places. Five screws were required to secure these parts. The redesigned mounting block subassembly also includes a leaf spring designed to replace the torsion spring found in the previous design. The pivot arm side plate, pivot arm block and the shoe could possibly be cast as one part, eliminating four redundant parts. The benefit in assembly savings would have to be weighed against the cost of having a mold made.

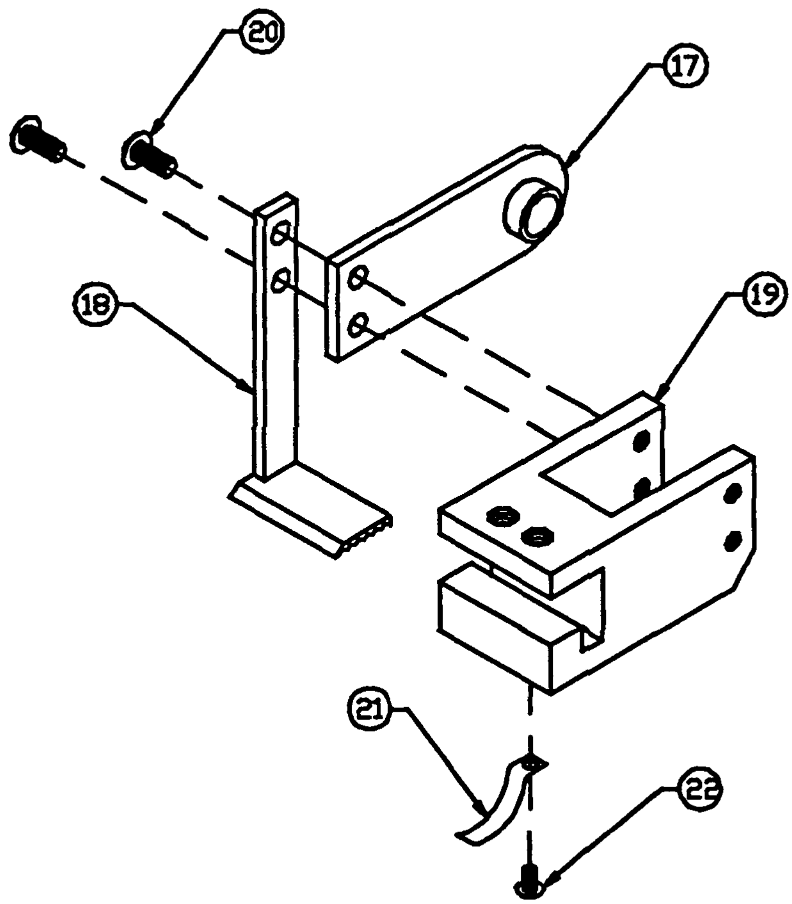


Figure 4.19 Redesigned mounting block subassembly.

The new pivoting subassembly (Figure 4.20) eliminates 10 of the 12 screws present in the previous design. This subassembly begins with the cylinder pin (23) being inserted into a side plate subassembly (24). The air cylinder of the drive subassembly (25) is then inserted over the cylinder pin while the pick wheel shaft is inserted into the bearing of the side plate subassembly. The side plate support (26) is added and held while the other side plate subassembly (27) is positioned and fastened with a screw (28). The partially-completed subassembly is then turned over, and another screw (29) is used to fasten the side plate support.

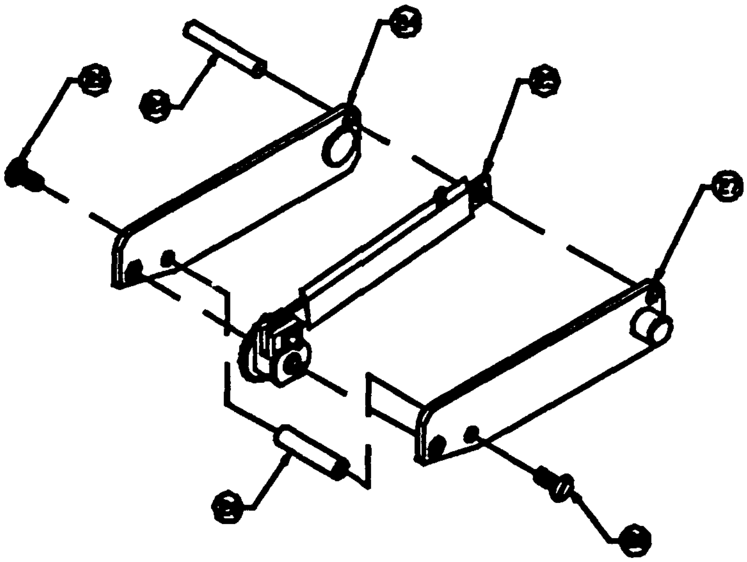


Figure 4.20 Redesigned pivoting subassembly.

The pivot pin of the pivoting subassembly (30) is inserted into the mounting block subassembly bearing (31), and the other pivot arm side plate (32) is attached with two screws (33). This completes the assembly of the Redesigned Clupicker (Figure 4.21).

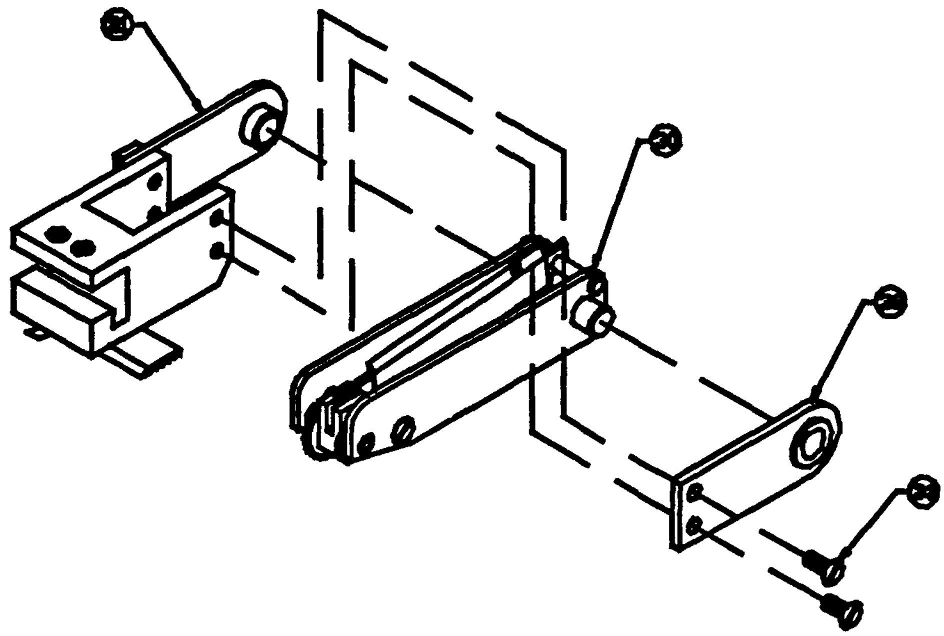


Figure 4.21 Redesigned Clupicker-- Final Assembly.

4.3.1 The Redesigned Clupicker-- DFA Methodology Analysis

An analysis of the Redesigned Clupicker using Boothroyd's systematic DFA methodology was also completed. Again, the analysis was conducted on each subassembly. When a subassembly appeared as a part in another subassembly, it was treated as a separate part. The assembly efficiencies were calculated for each subassembly, and the overall assembly efficiency was also calculated for the entire Modified Clupicker assembly.

The redesigned side plate subassembly shows a large improvement over the previous design. The side plate hub that was welded to the side plate was eliminated. Also, the elimination of the pivot pin screw and the reorientation necessary to secure the screw was made possible by press fitting the redesigned pivot pin. The total assembly time was reduced 73%-- from 46.33 seconds down to 12.23 seconds. The assembly efficiency was quadrupled from 6% to 24%. These design changes would result in a total savings of 57 cents for both side plate subassemblies. The DFA analysis results for this subassembly are presented in Table 4.5.

Table 4.5 DFA Analysis-- Redesigned side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Wheel Shaft Bearing	1	09	2.98	30	2.00	4.98	4.13	0
Pivot Pin	1	11	1.80	30	2.00	3.80	3.15	0
						12.23	10.15	

The full DFA methodology analysis is presented in Appendix D. A summary of these results can be found in Table 4.6.

Table 4.6 Redesigned Clupicker-- DFA Analysis.

Subassembly	No.	Assembly Time (seconds)	Assembly Efficiency (%)
Side Plate	2	24.46	24
Pick Wheel Hub	1	6.13	49
Pick Wheel	1	42.89	7
Drive	1	21.39	42
Pivot Arm Side Plate	2	7.25	41
Mounting Block	1	58.67	10
Pivoting	1	38.06	24
Redesigned Clupicker	1	30.95	29
Total Time:		237.05	

As mentioned previously, the assembly of the pick wheel hub subassembly was not changed. Combining these two parts would result in a part that would be difficult to manufacture.

The assembly time for the pick wheel subassembly was reduced by 8.64 seconds to 42.89 seconds resulting in a savings of 7 cents. The assembly efficiency was slightly increased from 6% to 7%. These improvements were made possible by the elimination of several spacers.

The cylinder subassembly of the Modified Clupicker was one of the worst in terms of assembly time and efficiency. The new drive subassembly that replaces the cylinder subassembly is much better. The assembly time was reduced by nearly 83% down to 21.39 seconds. This would produce a savings of 85 cents per subassembly. The assembly efficiency was improved by nearly 200%, from 14% to 42%. The elimination of 4 screws and many other parts was one of the major reasons for these great improvements.

In the Modified Clupicker design, the left pivot arm side plate and the right pivot arm side plate subassemblies required a total of 38.6 seconds to assemble and had a combined assembly efficiency of 16%. In the Redesigned Clupicker, the same side pivot arm plate subassembly is used on both the left and right sides. In addition to the manufacturing simplification that the use of standard parts provides, these two subassemblies can be assembled in less than half the time-- only 14.5 seconds. The assembly efficiency was also increased to 41%. The elimination of the pin rest allowed these improvements.

The redesigned mounting block shows only a 7 second improvement in assembly time. It can be assembled in 58.76 seconds, but the assembly efficiency was doubled to 10%. The elimination of three screws and a reorientation provided this improvement.

In the redesigned pivoting subassembly, 10 of the 12 screws and one of two reorientations were eliminated to cut the assembly time from 107.91 seconds to 38.06 seconds. The assembly efficiency was more than doubled from 11% to 24%.

The Redesigned Clupicker final assembly is basically the same as the final assembly for the Modified Clupicker except this assembly does not require the placement of a torsion spring. Also, one screw was eliminated. These changes resulted in a time savings of 24 seconds and an improvement in the assembly efficiency from 22% to 29%.

The Redesigned Clupicker has only 39 parts-- less than half the number of parts in the Modified Clupicker. The total time to assemble the Redesigned Clupicker is 237.05 seconds (3 minutes and 57 seconds). This is 43 percent of the time required to assemble the previous design. This time reduction would result in a savings of $2.62 per assembly. The overall assembly efficiency, calculated using the total number of non-redundant parts (17) and the total assembly time, is 21.5%-- nearly twice that of the Modified Clupicker.

4.3.2 The Redesigned Clupicker-- PDM Analysis

An analysis of the Redesigned Clupicker was also conducted using PDM. Subassemblies were treated the same as in the previous analyses.

The results of the PDM analysis of the redesigned side plate subassembly are shown in Table 4.7. The average combined merit of this part was slightly lowered by the redesign of the pivot pin (combined merit of 83 rather than the previous value of 97) because this pin must be press fit into the assembly. However, this press fit allowed for the elimination of a redundant part-- the screw that held the pin. The elimination of these two redundant parts (one screw in each side plate subassembly) raised the assembly merit from 17 to 28.

Table 4.7 PDM Analysis-- Redesigned side plate subassembly.

PART INPUT DATA

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Side Plate	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Wheel Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
3	Pivot Pin	VERT DOWN	N	PRESS FIT	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Side Plate	100	100	50	87	NO
2	Wheel Bearing	100	22	100	83	YES
3	Pivot Pin	100	22	100	83	YES

AVG COMBINED MERIT: 84 ASSEMBLY MERIT: 28

The full results for each subassembly can be found in Appendix D. The combined average merit and the assembly merit for each subassembly as well as the averages of both of these the merits are presented for both Clupicker designs in Table 4.8.

Table 4.8 Merit values from PDM analysis.

No.	Subassembly	Qty	Redesigned Clupicker		Modified Clupicker	
			ACM	AM	ACM	AM
1	Side Plate	2	84	28	86	17
2	Pick Wheel Hub	1	96	48	96	48
3	Pick Wheel	1	94	8	95	6
4	Drive	1	87	65	(85)	(28)
5	Pivot Arm Side Plate	2	84	42	(86)	(25)
6	Mounting Block	1	86	25	86	11
7	Pivoting	1	89	38	83	17
8	Redesigned Clupicker	1	86	52	82	47
	Averages:		87	37	88	26

As stated before, the assembly of the pick wheel hub subassembly was not modified. Only minor changes were made to the pick wheel subassembly. Some redundant parts were eliminated while others were added. The Assembly Merit of the redesigned pick wheel subassembly was only raised to 8 (from 5 in the previous design). Greater improvements could be made in this assembly by producing the pick wheel as a single part rather than the combination of five spacers and four blades.

The PDM analysis, as did the DFA methodology analysis, indicates that the new drive subassembly will be much easier to assemble than the cylinder subassembly used in the Modified Clupicker. The Assembly Merit of this new subassembly is 65-- nearly two and a half times greater than that of the cylinder subassembly. This subassembly has only one redundant part, whereas the cylinder subassembly had 10 redundant parts.

The design of the pivot arm side plate assembly received higher ratings than did the left and right pivot arm side plate assemblies of the Modified Clupicker. The average Assembly Merit of the two old subassemblies was 26, but the new subassembly received an Assembly Merit of 42. Again, the elimination of redundant parts led to this improvement.

The Assembly Merit of the redesigned mounting block subassembly was only slightly better than that of the previous design. Three redundant parts (screws) were removed, but another screw and leaf spring were added. This led to an Assembly Merit of 25.

Improvements made in the redesigned pivoting subassembly more than doubled its Assembly Merit from 17 to 38. The elimination of 10 of the 12 screws led to this increase.

The elimination of one redundant part raised the Assembly Merit of the Redesigned Clupicker final assembly slightly, from 47 to 52.

The average of the Average Combined Merits of all the subassemblies in the Redesigned Clupicker is 87. This value is slightly lower than that of the Modified Clupicker. In the effort to eliminate some redundant parts, other parts were made more difficult to insert, fasten, or feed. The payback, however, is in the Assembly merit. The average for the Redesigned Clupicker is 37. This is still not very high, but it represents a 42% increase over the Modified Clupicker's average Assembly merit.

4.4 Discussion of Results

Both of these methods of analysis indicate that the Redesigned Clupicker should be easier to assemble than the Modified Clupicker. Exactly how much easier is more difficult to determine.

For example, it is very doubtful that the Redesigned Clupicker will be assembled in exactly 237.05 seconds, or that the Modified Clupicker will be assembled in exactly 553.54 seconds. Boothroyd's analysis is based on approximations. On the whole, the approximations may average out. An overestimation in one spot may make up for an underestimation in another. What the designer should learn from this analysis is that the new design can be assembled in approximately half the time it took to assemble the previous design.

PDM should be used in the same way. The analysis should give the designer relative numbers to describe the ease of assembly of one design compared to another. PDM does not generate the large amount of information that a DFA analysis would, but it does give the designer a basis for comparison.

These analysis techniques should serve to make the designer aware that the ease of assembly of a product should be considered very early in the design stage.

4.5 Performance of Redesigned Clupicker Prototype

A prototype of the Redesigned Clupicker was completed and tests were conducted. A set of tests were run using the same seven military fabrics that were used with the Modified Clupicker. The results of these tests are presented in Table 4.9. As expected, the Redesigned Clupicker performed at the same high levels of efficiency as the Modified Clupicker. A total efficiency of 99.9% was attained over the 1800 picks attempted. The Redesigned Clupicker was also able to successfully pick each the fabrics in the Assorted Fabric pile mentioned previously. However, the Redesigned Clupicker had the same problems with fabrics 4, 5, and 6 that the Modified Clupicker had (some combination of fabrics 4, 5, and 6 was occasionally double picked).

Table 4.9 Military fabric test results for Redesigned Clupicker.

Fabric Number	Number of Picks	Missed Picks	Double Picks	Efficiency (%)
1	200	0	0	100
2	400	0	0	100
3	200	0	0	100
4	200	0	0	100
5	400	1	0	99.8
6	200	0	1	99.5
7	200	0	0	100

Chapter 5. Conclusion

The Clupicker has been redesigned based on DFA guidelines and using two different DFA analysis techniques. Not every guideline was followed, and not every redundant part was eliminated from the design. Manufacturing concerns were taken into account, and there are still areas of possible improvement-- the pick wheel assembly still contains many parts. But, this redesigned Clupicker should be much easier to assemble than the previous design-- it is estimated that it will require half the time to assemble.

Design for Assembly is an idea that can lead to great savings and increases in quality. Every part that is eliminated from the design is a part that does not have to be manufactured, stored, documented, and is a part that cannot be incorrectly produced or fail in service. In order to reap all its benefits, however, DFA must be considered early in the design process [4].

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Appendix A.

Fabrics Used in Testing

Military Fabrics Used

1. Description: Polyester/Wool cloth, Tropical, Blue SH 1578
   Military Specification: MIL-C-21115K, 18 Dec 87,Type 3, Class 3
   National Stock Number: 8305-01-057-7291

2. Description: Polyester/Cotton cloth, Broadcloth, AG-415
   Military Specification: MIL-C-43992A, 10 May 85, Class 5
   National Stock Number: 8305-01-074-1843

3. Description: Cotton/Nylon cloth, Woodland Camouflage (Printed)
   Military Specification: MIL-C-44031D, 22 Aug 89, Class 1
   National Stock Number: 8305-01-087-1329

4. Description: Polyester/Cotton cloth, Durable press
   Military Specification: MIL-C-43791B, 13 Feb 79, Type 2, Class 1
   National Stock Number: 8305-01-033-4410

5. Description: Polyester/Cotton cloth, for pockets
   Military Specification: MIL-C-43718C, 17 Jun 88, Class 1
   National Stock Number: 8305-01-062-7490

6. Description: Nylon cloth, Taffeta
   Military Specification: MIL-C-21852F, 6 Feb 89, Type 2
   National Stock Number: Unknown

7. Description: Cotton cloth, Camouflage Pattern, Wind Resistant Poplin, Ripstock
   Military Specification: MIL-C-43468F, 26 Jul 88, Type 3
   National Stock Number: 8305-01-167-8403

Assorted Fabric Pile

1. Shirting, 40% Polyester / 60% Cotton, Blue
2. 100% Polyester, Gray, 4-6 oz/sq yd
3. 100% Synthetic Filament, White/Brown Striped, Stiff
4. Tyvek PC, Non-woven
5. 65% Polyester / 35% Cotton, White, 4-6 oz/sq yd
6. Non-woven, White, 2-3 oz/sq yd
7. Table Cloth, 100% Polyester, Red/White Checked
8. Land's End Shirting, 100% Cotton, White
9. 100% Synthetic Filament, Yellow, Smooth, Slick, 3-4 oz/sq yd
10. Work Pant Material, 72% Polyester / 28% Cotton, Navy, 8-10 oz/sq yd
11. Non-woven, White, 1-2 oz/sq yd
12. Military Dress Shirt Material, 65% Polyester / 35% Cotton, Blue
13. 100% Polyester, Peach, 6-8 oz/sq yd
14. Non-Woven, White, 2-3 oz/sq yd
15. 100% Polyester, Cream, 6-8 oz/sq yd
16. Land's End Shirting, 100% cotton, Pink
17. Non-woven, White, 2-3 oz/sq yd

18. Chambray, Cotton/Polyester cloth, Blue
    NSN 8305-01-074-4878, 3-4 oz/sq yd

19. Acxel 35, Non-woven, White, 3-5 oz/sq yd

20. Leisure Suit Material, 100% Polyester, Brown, 5-7 oz/sq yd

21. Shirting Material, Blue

Appendix B.

Modified Clupicker

DFA Analysis Results

Table B.1 DFA Analysis-- Side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Side Plate Hub	1	11	1.80	96	12.00	13.80	11.45	0
Wheel Shaft Bearing	1	09	2.98	30	2.00	4.98	4.13	0
Pivot Pin	1	11	1.80	06	5.50	7.30	6.06	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Screw (Pivot Pin)	1	11	1.80	38	6.00	7.80	6.47	0
						46.33	38.45	

Table B.2 DFA Analysis-- Cylinder subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Air Cylinder	1	20	1.80	00	1.50	3.30	2.74	1
Air Cylinder Mounting Block	2	32	1.95	06	5.50	14.90	12.37	0
Large Cylinder Nut	2	00	1.13	38	6.00	14.26	11.84	0
Spring	1	01	1.43	00	1.50	2.93	2.43	1
Spring	1	01	1.43	00	1.50	2.93	2.43	1
Rod-End Block	2	20	1.80	38	6.00	15.60	12.95	0
Small Belt Clamp Nut	2	01	1.43	38	6.00	14.86	12.33	0
Timing Belt	1	23	2.36	08	6.50	8.86	7.35	1
Belt Clamp	2	21	2.10	06	5.50	15.20	12.62	1
Screw (Belt Clamp)	4	11	1.80	38	6.00	31.20	25.90	0
						124.04	102.95	

Table B.3 DFA Analysis-- Back pulley subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pivot End Shaft	1	00	1.13	00	1.50	2.63	2.18	1
Spacer	1	01	1.43	00	1.50	2.93	2.43	0
Pivot and Pulley	1	00	1.13	00	1.50	2.63	2.18	1
Spacer	1	01	1.43	00	1.50	2.93	2.43	0
						11.12	9.23	

Table B.4 DFA Analysis-- Pick wheel hub subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pick Wheel Shaft	1	00	1.13	00	1.50	2.63	2.18	1
Pick Wheel Hub	1	01	1.50	30	2.00	3.50	2.91	0
						6.13	5.09	

Table B.5 DFA Analysis-- Pick wheel subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pick Wheel Hub Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Spacer	1	01	1.43	00	1.50	2.93	2.43	0
Pick Wheel Spacer	5	03	1.69	00	1.50	15.95	13.24	0
Pick Wheel Blade	4	03	1.69	00	1.50	12.76	10.59	0
Shim	1	03	1.69	00	1.50	3.19	2.65	0
Shim	1	03	1.69	00	1.50	3.19	2.65	0
Pick Wheel Pulley	1	00	1.13	38	6.00	7.13	5.92	0
Spacer	1	01	1.43	00	1.50	2.93	2.43	0
						51.53	42.77	

Table B.6 DFA Analysis-- Right pivot arm side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Right Pivot Arm Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Bearing	1	11	1.80	30	2.00	3.80	3.15	0
Pin Rest	1	11	1.80	06	5.50	7.30	6.06	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Screw (Pin Rest)	1	11	1.80	38	6.00	7.80	6.47	0
						31.35	26.02	

Table B.7 DFA Analysis-- Mounting block subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pivot Arm Block	1	30	1.95	00	1.50	3.45	2.86	1
Right Pivot Arm Side Plate Subass'y	1	30	1.95	06	5.50	7.45	6.18	0
Screw (Right Pivot Arm Side Plate)	3	11	1.80	38	6.00	23.40	19.42	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Knurled Shoe	1	30	1.95	06	5.50	7.45	6.18	0
Screw (Shoe)	2	11	1.80	38	6.00	15.60	12.96	0
						66.35	55.07	

Table B.8 DFA Analysis-- Pivoting subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Cylinder Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Side Plate Subass'y	1	30	1.95	08	6.50	8.45	7.01	0
Screw (Mounting Block)	4	11	1.80	38	6.00	31.20	25.90	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Back Pulley Subass'y	1	30	1.95	31	5.00	6.95	5.77	1
Pick Wheel Subass'y	1	30	1.95	31	5.00	6.95	5.77	1
Side Plate Support	2	10	1.43	09	7.50	17.86	14.82	0
Side Plate Subass'y	1	30	1.95	08	6.50	8.45	7.01	1
Screw (Support)	2	11	1.80	38	6.00	15.60	12.95	0
Screw (Mounting Block)	3	11	1.80	38	6.00	23.40	19.42	0
Screw (Spring Pin)	1	10	1.50	38	6.00	7.50	6.23	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Screw (Support)	2	11	1.80	38	6.00	15.60	12.95	0
						107.91	89.57	

Table B.9 DFA Analysis-- Left pivot arm side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Left Pivot Arm Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Bearing	1	11	1.80	30	2.00	3.80	3.15	0
Screw (Spring Pin)	1	10	1.50	38	6.00	7.50	6.23	0
						7.25	6.02	

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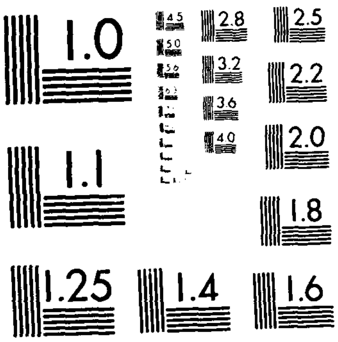

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Table B.10 DFA Analysis-- Modified Clupicker final assembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Mounting Block Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Pivoting Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Left Pivot Arm Side Plate Subass'y	1	30	1.95	08	6.50	8.45	7.01	1
Screw (Left Pivot Plate)	3	11	1.80	39	8.00	29.40	24.40	0
Torsion Spring	1	30	1.95	44	8.50	10.45	8.67	1
						55.20	45.82	

Appendix C.

Modified Clupicker

PDM Analysis Results

MODIFIED CLIPICKER PDM ANALYSIS

PART INPUT DATA

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Side Plate	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Side Plate Hub	VERT DOWN	Y	WELD	VIB BOWL	YES
3	Wheel Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
4	Pivot Pin	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
5	Screw(pivot)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Side Plate	100	100	60	87	NO
2	Side Plate Hub	92	0	100	78	YES
3	Wheel Bearing	100	22	100	83	YES
4	Pivot Pin	92	100	100	97	YES
5	Screw (Pivot)	100	44	100	86	YES

AVG COMBINED MERIT: 86 ASSEMBLY MERIT: 17

PART INPUT DATA

ASSEMBLY: Cylinder Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Air Cylinder	VERT DOWN	N	SLIP/SLIDE	STAND PALLET	NO
2	Cyl Mounting Block	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
3	Cyl Mounting Block	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
4	Large Cyl Nut	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Large Cyl Nut	VERT DOWN	N	SCREW	VIB BOWL	YES
6	Spring 1	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
7	Spring 2	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
8	Rod End Block	VERT DOWN	N	SCREW	VIB BOWL	YES
9	Rod End Block	VERT DOWN	N	SCREW	VIB BOWL	YES
10	Small Clamp Nut	VERT DOWN	N	SCREW	VIB BOWL	YES
11	Small Clamp Nut	VERT DOWN	N	SCREW	VIB BOWL	YES
12	Timing Belt	COMB/V,H,A,R	Y	SLIP/SLIDE	SPEC HANDLE	NO
13	Belt Clamp	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
14	Belt Clamp	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
15	Screw (Belt)	VERT DOWN	N	SCREW	VIB BOWL	YES
16	Screw (Belt)	VERT DOWN	N	SCREW	VIB BOWL	YES
17	Screw (Belt)	VERT DOWN	N	SCREW	VIB BOWL	YES
18	Screw (Belt)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Cylinder Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Air Cylinder	100	100	33	84	NO
2	Cyl Mounting Block	100	100	83	95	YES
3	Cyl Mounting Block	100	100	83	95	YES
4	Large Cyl Nut	100	44	100	86	YES
5	Large Cyl Nut	100	44	100	86	YES
6	Spring 1	100	100	50	87	NO
7	Spring 2	100	100	50	87	NO
8	Rod End Block	100	44	83	79	YES
9	Rod End Block	100	44	83	79	YES
10	Small Clamp Nut	100	44	100	86	YES
11	Small Clamp Nut	100	44	100	86	YES
12	Timing Belt	8	100	17	59	NO
13	Belt Clamp	92	100	83	92	NO
14	Belt Clamp	92	100	83	92	NO
15	Screw (Belt)	100	44	100	86	YES
16	Screw (Belt)	100	44	100	86	YES
17	Screw (Belt)	100	44	100	86	YES
18	Screw (Belt)	100	44	100	86	YES

AVG COMBINED MERIT: 85 ASSEMBLY MERIT: 28

PART INPUT DATA

ASSEMBLY: Back Pulley Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pivot End Shaft	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
2	Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
3	Pivot End Pulley	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	NO
4	Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Back Pulley Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pivot End Shaft	92	100	100	97	NO
2	Spacer	100	100	100	100	YES
3	Pivot End Pulley	100	100	100	100	NO
4	Spacer	100	100	100	100	YES

AVG COMBINED MERIT: 99 ASSEMBLY MERIT: 50

PART INPUT DATA

ASSEMBLY: Pick Wheel Hub Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pick Wheel Shaft	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
2	Pick Wheel Hub	VERT DOWN	N	SNAP/PRESS	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pick Wheel Hub Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pick Wheel Shaft	92	100	100	97	NO
2	Pick Wheel Hub	100	89	100	96	YES

AVG COMBINED MERIT: 96 ASSEMBLY MERIT: 48

PART INPUT DATA

ASSEMBLY: Pick Wheel Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pick Wheel Hub SA	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
2	Spacer	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
3	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
4	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
5	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
6	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
7	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
8	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
9	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
10	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
11	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
12	Shim	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
13	Shim	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
14	Pick Wheel Pulley	VERT DOWN	N	SCREW	VIB BOWL	YES
15	Spacer	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pick Wheel Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pick Wheel Hub SA	92	100	83	92	NO
2	Spacer	92	100	100	97	YES
3	Pick Wheel Spacer	100	100	83	95	YES
4	Pick Wheel Blade	100	100	83	95	YES
5	Pick Wheel Spacer	100	100	83	95	YES
6	Pick Wheel Blade	100	100	83	95	YES
7	Pick Wheel Spacer	100	100	83	95	YES
8	Pick Wheel Blade	100	100	83	95	YES
9	Pick Wheel Spacer	100	100	83	95	YES
10	Pick Wheel Blade	100	100	83	95	YES
11	Pick Wheel Spacer	100	100	83	95	YES
12	Shim	100	100	100	100	YES
13	Shim	100	100	100	100	YES
14	Pick Wheel Pulley	100	44	100	86	YES
15	Spacer	92	100	100	97	YES

AVG COMBINED MERIT: 95 ASSEMBLY MERIT: 6

PART INPUT DATA

ASSEMBLY: Right Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Rt Pvt Arm Sd Plate	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
2	Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
3	Pin Rest	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
4	Screw (Pin Rest)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Right Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Rt Pvt Arm Sd Plate	92	100	50	84	NO
2	Bearing	100	22	100	83	YES
3	Pin Rest	92	100	100	97	YES
4	Screw (Pin Rest)	100	44	100	86	YES

AVG COMBINED MERIT: 88 ASSEMBLY MERIT: 22

PART INPUT DATA

ASSEMBLY: Mounting Block Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pivot Arm Block	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
2	Rt PA Sd Plate SA	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	YES
3	Screw (Rt Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
4	Screw (Rt Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Screw (Rt Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
6	Shoe	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
7	Screw (Shoe)	VERT DOWN	N	SCREW	VIB BOWL	YES
8	Screw (Shoe)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Mounting Block Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pivot Arm Block	92	100	50	84	NO
2	Rt PA Sd Plate SA	92	100	50	84	YES
3	Screw (Rt Pivot Arm)	100	44	100	86	YES
4	Screw (Rt Pivot Arm)	100	44	100	86	YES
5	Screw (Rt Pivot Arm)	100	44	100	86	YES
6	Shoe	92	100	83	92	YES
7	Screw (Shoe)	100	44	100	86	YES
8	Screw (Shoe)	100	44	100	86	YES

AVG COMBINED MERIT: 86 ASSEMBLY MERIT: 11

PART INPUT DATA

ASSEMBLY: Pivoting Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Cylinder SA	VERT DOWN	Y	SLIP/SLIDE	STAND PALLET	NO
2	Side Plate SA	VERT DOWN	N	SLIP/SLIDE	STAND PALLET	YES
3	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
4	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
6	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
7	Back Pulley SA	ANGLE	N	SNAP/PRESS	STAND PALLET	NO
8	Pick Wheel SA	ANGLE	N	SNAP/PRESS	STAND PALLET	NO
9	Side Plate Support	COMB/V,H,A,R	Y	SLIP/SLIDE	VIB BOWL	YES
10	Side Plate Support	COMB/V,H,A,R	Y	SLIP/SLIDE	VIB BOWL	YES
11	Side Plate SA	VERT DOWN	N	SLIP/SLIDE	STAND PALLET	NO
12	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES
13	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES
14	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
15	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
16	Screw(Mount Block)	VERT DOWN	N	SCREW	VIB BOWL	YES
17	Screw (Spring)	VERT DOWN	N	SCREW	VIB BOWL	YES
18	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES
19	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pivoting Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Cylinder SA	92	100	33	81	NO
2	Side Plate SA	100	100	33	84	YES
3	Screw (Mount Block)	100	44	100	86	YES
4	Screw (Mount Block)	100	44	100	86	YES
5	Screw (Mount Block)	100	44	100	86	YES
6	Screw (Mount Block)	100	44	100	86	YES
7	Back Pulley SA	67	89	33	67	NO
8	Pick Wheel SA	67	89	33	67	NO
9	Side Plate Support	8	100	100	82	YES
10	Side Plate Support	8	100	100	82	YES
11	Side Plate SA	100	100	33	84	NO
12	Screw (Support)	100	44	100	86	YES
13	Screw (Support)	100	44	100	86	YES
14	Screw (Mount Block)	100	44	100	86	YES
15	Screw (Mount Block)	100	44	100	86	YES
16	Screw (Mount Block)	100	44	100	86	YES
17	Screw (Spring)	100	44	100	86	YES
18	Screw (Support)	100	44	100	86	YES
19	Screw (Support)	100	44	100	86	YES

AVG COMBINED MERIT: 83 ASSEMBLY MERIT: 17

PART INPUT DATA

ASSEMBLY: Left Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	L Piv Arm Sd Plate	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
2	Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
3	Screw (Spring)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Left Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	L Piv Arm Sd Plate	92	100	50	84	NO
2	Bearing	100	22	100	83	YES
3	Screw (Spring)	100	44	100	86	YES

AVG COMBINED MERIT: 84 ASSEMBLY MERIT: 28

PART INPUT DATA

ASSEMBLY: Modified Clupicker

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Mounting Block SA	VERT DOWN	N	SLIP/SLIDE	STAND PALLET	NO
2	Pivoting SA	VERT DOWN	N	SLIP/SLIDE	STAND PALLET	NO
3	L P Arm S Plate SA	VERT DOWN	Y	SLIP/SLIDE	STAND PALLET	NO
4	Screw (L Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Screw (L Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
6	Screw (L Pivot Arm)	VERT DOWN	N	SCREW	VIB BOWL	YES
7	Torsion Spring	COMB/V,H,A	N	CLIP/SNAP	VIB BOWL	NO

MERIT ANALYSIS RESULTS

ASSEMBLY: Modified Clupicker

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Mounting Block SA	100	100	33	84	NO
2	Pivoting SA	100	100	33	84	NO
3	L P Arm S Plate SA	92	100	33	81	NO
4	Screw (L Pivot Arm)	100	44	100	86	YES
5	Screw (L Pivot Arm)	100	44	100	86	YES
6	Screw (L Pivot Arm)	100	44	100	86	YES
7	Torsion Spring	50	78	67	68	NO

AVG COMBINED MERIT: 82 ASSEMBLY MERIT: 47

Appendix D.

Redesigned Clupicker

DFA Analysis Results

Table D.1 DFA Analysis-- Redesigned side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Wheel Shaft Bearing	1	09	2.98	30	2.00	4.98	4.13	0
Pivot Pin	1	11	1.80	30	2.00	3.80	3.15	0
						12.23	10.15	

Table D.2 DFA Analysis-- Redesigned pick wheel hub subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pick Wheel Shaft	1	00	1.13	00	1.50	2.63	2.18	1
Pick Wheel Hub	1	01	1.50	30	2.00	3.50	2.91	0
						6.13	5.09	

Table D.3 DFA Analysis-- Redesigned pick wheel subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pick Wheel Hub Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Pick Wheel Spacer	5	03	1.69	00	1.50	15.95	13.24	0
Pick Wheel Blade	4	03	1.69	00	1.50	12.76	10.59	0
Driven Link	1	20	1.80	00	1.50	3.30	2.74	0
Nut	1	01	1.43	38	6.00	7.43	6.17	0
						42.89	35.60	

Figure D.4 DFA Analysis-- Drive subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Air Cylinder	1	30	1.95	00	1.50	3.45	2.86	1
Pick Wheel Subass'y	1	30	1.95	31	5.00	6.95	5.77	1
Connecting Pin	1	00	1.13	00	1.50	2.63	2.18	1
Retaining Ring	2	04	2.18	30	2.00	8.36	6.94	0
						21.39	17.75	

Table D.5 DFA Analysis-- Redesigned pivot arm side plate subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pivot Arm Side Plate	1	30	1.95	00	1.50	3.45	2.86	1
Bearing	1	11	1.80	30	2.00	3.80	3.15	0
						7.25	6.02	

Table D.6 DFA Analysis-- Redesigned mounting block subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Pivot Arm Block	1	30	1.95	00	1.50	3.45	2.86	1
Pivot Arm Side Plate Subass'y	1	30	1.95	06	5.50	7.45	6.18	0
Knurled Shoe	1	30	1.95	06	5.50	7.45	6.18	0
Screw (Pivot Arm Side Plate)	2	11	1.80	38	6.00	15.60	12.95	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Leaf Spring	1	33	2.51	06	5.50	8.01	6.65	1
Screw (Spring)	1	11	1.80	38	6.00	7.80	6.47	0
						58.76	48.77	

Table D.7 DFA Analysis-- Redesigned pivoting subassembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Side Plate Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Cylinder Pin	1	00	1.13	00	1.50	2.63	2.18	0
Drive Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Side Plate Support	1	10	1.43	06	5.50	6.93	5.75	0
Side Plate Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Screw (Support)	1	11	1.80	38	6.00	7.80	6.47	0
** Reorientation **	1			98	9.00	9.00	7.47	0
Screw (Support)	1	11	1.80	38	6.00	7.80	6.47	0
						38.06	31.59	

Table D.8 DFA Analysis-- Redesigned Clupicker final assembly.

Part	RP	HC	TH	IC	TI	TA	CA	NM
Mounting Block Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Pivoting Subass'y	1	30	1.95	00	1.50	3.45	2.86	1
Pivot Arm Side Plate Subass'y	1	30	1.95	08	6.50	8.45	7.01	1
Screw (Left Pivot Plate)	2	11	1.80	38	6.00	15.60	12.95	0
						30.95	25.69	

Appendix E.

Redesigned Clupicker

PDM Analysis Results

REDESIGNED CLUPICKER PDM ANALYSIS

PART INPUT DATA

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Side Plate	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Wheel Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES
3	Pivot Pin	VERT DOWN	N	PRESS FIT	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Side Plate	100	100	50	87	NO
2	Wheel Bearing	100	22	100	83	YES
3	Pivot Pin	100	22	100	83	YES

AVG COMBINED MERIT: 84 ASSEMBLY MERIT: 28

PART INPUT DATA

ASSEMBLY: Pick Wheel Hub Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pick Wheel Shaft	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
2	Pick Wheel Hub	VERT DOWN	N	SNAP/PRESS	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pick Wheel Hub Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pick Wheel Shaft	92	100	100	97	NO
2	Pick Wheel Hub	100	89	100	96	YES

AVG COMBINED MERIT: 96 ASSEMBLY MERIT: 48

PART INPUT DATA

ASSEMBLY: Pick Wheel Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pick Wheel Hub SA	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
2	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
3	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
4	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
5	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
6	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
7	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
8	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
9	Pick Wheel Blade	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
10	Pick Wheel Spacer	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
11	Driven Link	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
12	Nut	VERT DOWN	N	NUT/BOLT	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pick Wheel Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pick Wheel Hub SA	92	100	83	92	NO
2	Pick Wheel Spacer	100	100	83	95	YES
3	Pick Wheel Blade	100	100	83	95	YES
4	Pick Wheel Spacer	100	100	83	95	YES
5	Pick Wheel Blade	100	100	83	95	YES
6	Pick Wheel Spacer	100	100	83	95	YES
7	Pick Wheel Blade	100	100	83	95	YES
8	Pick Wheel Spacer	100	100	83	95	YES
9	Pick Wheel Blade	100	100	83	95	YES
10	Pick Wheel Spacer	100	100	83	95	YES
11	Driven Link	100	100	100	100	YES
12	Nut	100	33	100	84	YES

AVG COMBINED MERIT: 94 ASSEMBLY MERIT: 8

PART INPUT DATA

ASSEMBLY: Drive Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Air Cylinder	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
2	Pick Wheel SA	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
3	Connecting Pin	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
4	Retaining Ring	VERT DOWN	N	CLIP/SNAP	PRECIS PALLET	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Drive Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Air Cylinder	92	100	50	84	NO
2	Pick Wheel SA	92	100	67	87	NO
3	Connecting Pin	92	100	100	97	NO
4	Retaining Ring	100	78	50	79	YES

AVG COMBINED MERIT: 87 ASSEMBLY MERIT: 65

PART INPUT DATA

ASSEMBLY: Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pivot Arm Sd Plate	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
2	Bearing	VERT DOWN	N	PRESS FIT	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pivot Arm Side Plate Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pivot Arm Sd Plate	92	100	50	84	NO
2	Bearing	100	22	100	83	YES

AVG COMBINED MERIT: 84 ASSEMBLY MERIT: 42

PART INPUT DATA

ASSEMBLY: Mounting Block Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Pivot Arm Block	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Piv Arm Sd Plate SA	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	YES
3	Shoe	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
4	Screw (Side Plate)	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Screw (Side Plate)	VERT DOWN	N	SCREW	VIB BOWL	YES
6	Leaf Spring	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	NO
7	Screw (Spring)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Mounting Block Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Pivot Arm Block	100	100	50	87	NO
2	Piv Arm Sd Plate SA	92	100	50	84	YES
3	Shoe	92	100	67	87	YES
4	Screw (Side Plate)	100	44	100	86	YES
5	Screw (Side Plate)	100	44	100	86	YES
6	Leaf Spring	92	100	67	87	NO
7	Screw (Spring)	100	44	100	86	YES

AVG COMBINED MERIT: 86 ASSEMBLY MERIT: 25

PART INPUT DATA

ASSEMBLY: Pivoting Subassembly

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Side Plate SA	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Cylinder Pin	VERT DOWN	N	SLIP/SLIDE	VIB BOWL	YES
3	Drive SA	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
4	Side Plate Support	VERT DOWN	Y	SLIP/SLIDE	VIB BOWL	YES
5	Side Plate SA	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
6	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES
7	Screw (Support)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Pivoting Subassembly

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR *ELIMINATION*
1	Side Plate SA	100	100	50	87	NO
2	Cylinder Pin	100	100	83	95	YES
3	Drive SA	100	100	50	87	NO
4	Side Plate Support	92	100	100	97	YES
5	Side Plate SA	92	100	50	84	NO
6	Screw (Support)	100	44	100	86	YES
7	Screw (Support)	100	44	100	86	YES

AVG COMBINED MERIT: 89 ASSEMBLY MERIT: 38

PART INPUT DATA

ASSEMBLY: Redesigned Clupicker

PART NUMBER	PART NAME	INSERTION DIRECTION	HOLD DOWN	FASTENING PLACEMENT	FEEDING PRESENTATION	CANDIDATE FOR ELIMINATION
1	Mounting Block SA	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
2	Pivoting SA	VERT DOWN	N	SLIP/SLIDE	PRECIS PALLET	NO
3	Piv Arm Sd Plate SA	VERT DOWN	Y	SLIP/SLIDE	PRECIS PALLET	NO
4	Screw (Side Plate)	VERT DOWN	N	SCREW	VIB BOWL	YES
5	Screw (Side Plate)	VERT DOWN	N	SCREW	VIB BOWL	YES

MERIT ANALYSIS RESULTS

ASSEMBLY: Redesigned Clupicker

PART NUMBER	PART NAME	INSERTION MERIT	FASTENING MERIT	FEEDING MERIT	COMBINED MERIT	CANDIDATE FOR ELIMINATION
1	Mounting Block SA	100	100	50	87	NO
2	Pivoting SA	100	100	50	87	NO
3	Piv Arm Sd Plate SA	92	100	50	84	NO
4	Screw (Side Plate)	100	44	100	86	YES
5	Screw (Side Plate)	100	44	100	86	YES

AVG COMBINED MERIT: 86 ASSEMBLY MERIT: 52